Agricultural Research Updates

Volume 20

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Editors
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Chapter 1 – The impact of global and local forces on the change in pricing policy in the food market depends on the production of agricultural crops in major producing regions that have a direct access to the world market. The latest predictions show that in the period until 2050 there will be a need to increase agricultural production by 60% worldwide, in order to meet the increasing demand from a growing population. The countries of the former Soviet Union – Kazakhstan, Russia and Ukraine in particular, have the greatest potential to increase food supply and food security in the world. Therefore, a study of the historical development of the agricultural sector, the current state
of agricultural policy and assessment of the export potential of the countries of the former Soviet Union is very important. The chapter examines the main geographical patterns of change in land productivity over the past 100 years of the development of agriculture in the south of Ukraine. It determines the spatial and temporal trends of changes in the conditions of the climate system and their impact on the dynamics of bio-productivity in the last century. The chapter also considers historical and contemporary global trends in the formation of the grain market, and identifies the role and place of Ukraine in it.

Chapter 2 – This review sought to provide information on cultivation, common diseases, and properties of watermelon, as well as a potential pharmaceuticals agent. Apart from disseminating details on growing of red- and yellow-fleshed watermelon plants from seed germination to harvesting, in this review we also focused on the insect pests and diseases that affect the watermelon plant and insecticidal control of these pests, a most commonly practiced in Malaysia. The presence of nutritional composition, as well as the bioactive compounds of watermelon fruit were also covered. In the present socio-economic scenario, searching, and practicing the proper cultivation technique and appropriate handling of tropical fruit, such as watermelon, could support the local population who depend on farming for a livelihood. Knowledge on the growth requirements and the potential insecticidal control of insect pests and diseases will facilitate large scale production and commercialization of the watermelon for international market. In addition, watermelon plants are widely cultivated for its large, sweet, juicy, and refreshing edible flesh, but there is also a need to ensure that their potential uses is exploited for its potential health benefits. Overall, the information on cultivation, common diseases, and properties of watermelon could provide a wide range of social and economic benefits, especially for food and pharmaceutical industries.

Chapter 3 – This research aimed to evaluate the production of beans cowpea fertigated with Human urine associated with Cassava Wastewater as an alternative source of nutrients. The experiment was conducted in a greenhouse located in the Campus I of the Federal University of Campina Grande. The treatments consists in fertigation with mineral fertilizers, organic fertilizers compound of humane urine and Cassava Wastewater and organomineral composed of Human urine, Cassava Wastewater and minerals consisting of NPK. It was concluded that the seven variables analyzed only two showed a significant difference between the means; the fertigation with only Cassava Wastewater promoted the maximum average number of pods per
plant, dry weight of 100 grains, dry mass of roots and harvest index and the use of Human urine or Cassava Wastewater can replace mineral fertilizer consists of NPK in culture cowpea.

Chapter 4 – Estimation of technological quality of wheat is always connected with possibility that the mixture of wheat flour and water form dough with unique rheological properties, which is not the case with other cereal flours. Numerous surveys have shown that gluten proteins (gliadins and glutenins), originating from endosperm of wheat kernel, are the key factor for viscoelastic properties of dough and end-use quality of wheat flour. Since a unique system for identification of all gluten proteins does not exist, various techniques are used for their accurate and precise determination. In the last decade, special attention has been given to the development of the microfluidic or Lab-on-a-Chip (LoaC) devices which are used for sensitive chemical and biological analyses. Also, it is worth to note that LoaC devices have found application for determination of gluten proteins. Therefore, this chapter will be focussed on the possibility of LoaC platforms application for identification and quantification of wheat gluten proteins as well as their connection with technological quality of wheat. Additionally, the current chapter is intended to highlight the great potential of LoaC technique for fast, accurate and high-throughput identification and quantification of wheat gluten proteins.

Chapter 5 – Effective greenhouse gas (GHG) mitigation strategies lead to win-win situations of reducing GHG emissions while improving productivity and likely farm profit. This chapter discusses several dairy farm management strategies that can be manipulated to reach such win-win situations. These include: 1) nutrition (diet formulation, feed efficiency, feed additives, and grazing management), 2) genetics and culling, 3) manure management, and 4) reproduction and health. The general effect of direct GHG gas mitigation strategies can be visualized.
Chapter 1

THE DEVELOPMENT AND CURRENT STATE OF THE AGRICULTURAL SECTOR OF THE NATIONAL ECONOMY DUE TO THE MORE ACTIVE ACCESS TO THE GLOBAL FOOD MARKET

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ABSTRACT

The impact of global and local forces on the change in pricing policy in the food market depends on the production of agricultural crops in major producing regions that have a direct access to the world market. The latest predictions show that in the period until 2050 there will be a need to increase agricultural production by 60% worldwide, in order to meet the increasing demand from a growing population. The countries of the former Soviet Union – Kazakhstan, Russia and Ukraine in particular, have the greatest potential to increase food supply and food security in the world. Therefore, a study of the historical development of the

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agricultural sector, the current state of agricultural policy and assessment of the export potential of the countries of the former Soviet Union is very important. The paper examines the main geographical patterns of change in land productivity over the past 100 years of the development of agriculture in the south of Ukraine. It determines the spatial and temporal trends of changes in the conditions of the climate system and their impact on the dynamics of bio-productivity in the last century. The paper also considers historical and contemporary global trends in the formation of the grain market, and identifies the role and place of Ukraine in it.

**Keywords:** international trade, export, grain market, agricultural products, climatic change, soil fertility

1. **Introduction**

Influence of global and local forces upon price policy on food sale market depends on production of crops in the main agricultural regions (Davenport et al., 2016); besides, trade of wheat, maize and soy is one the most stable estimation indices of state export potential on international future markets (Jia et al., 2016). Stimulus of regional integration of stock exchange market and stock return pricing all over the world are determinants being subdivided into three categories: individual market performance, macroeconomic conditions, and agricultural trade (Valdes et al., 2016). In big countries functioning of export control and price policy formation is determined by large exporters having a direct world market entry up to 67%. This effect is transferred inside the country to other regions through interregional trade flows. In small countries regional differences of internal effects of price measures are insignificant (Götz et al., 2016). Therefore, it has been offered, first of all, to differentiate nonfunctioning links of agricultural market and links properly adjusted to unfavorable conditions in developing and emerging countries that may ensure an increased stability to external changes of price policy and growth of food security (Brosig et al., 2016). Earlier (Schindler et al., 2016) it has been emphasized that provision of stability of consequences of agriculture development measures being planned, so called upgrading strategies (UPS), for the purpose of rise in national food security can be achieved due to an approach that simultaneously considers social, economic and environmental problems. From standpoint of efficient solutions of complicated internal optimization problems, the agricultural supply chains may finally impact food security. To this end, the Canadian wheat handling system is a complex export

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oriented supply chain that is currently undergoing extensive changes with respect to quality control. Developing analytic and simulation models of this supply chain with the ultimate goal of identifying effective wheat quality testing strategies in a complex operational and regulatory environment (Ge et al., 2015). Y. Zhu considered interaction mechanism of international trade and food security in different aspects, on example of China, the framework of The Food and Agriculture Organization of the United Nations and represented domestic and policy implications in the context of WTO (Zhu, 2016). Owing to this H. Cai and Y. Song suggested to apply innovative network theories to study positions of countries in international agricultural trade and simulation of probable consequences after break of bilateral agricultural raw material trade relations (Cai & Song, 2016). For contribution to the promotion of sustainable rural development throughout the EU community new European Agricultural Fund for Rural Development (EAFRD) was purposely established. Stability of the multiregional model EAFRD permits to examine trade relations within the framework of entire EU regions, as well as EU relations with other world regions. Besides, the model permits to determine losses or revenues of a large range of effects. On the other hand, this framework allows a simultaneous consideration of socioeconomic and environmental fund effects to identify their causes and flows and to clarify and reallocate benefits and responsibilities across levels and regions (Monsalve et al., 2016).

In 21st century the world demand for agricultural products is going to rise, recent forecasts show a need to increase agricultural production globally by 60% from 2005 to 2050, in order to meet a rising demand from a growing population. It requires scientific grounding of drivers for increase of foodstuffs production with simultaneous keeping social and environmental balance in use of water and land resources, preservation of biological diversity and satisfaction of population needs for foodstuffs. Production rise in agriculture significantly depends on strengthening of existing agricultural systems (Levers et al., 2016) against situational forecasting of world economy using the model Global Trade Analysis Project (GTAP) for the purpose of simulation of a move to global free trade (the maximum benefit from a multilateral trade reform) with endogenous and counterfactual modes of farmers’ aid policy in economic development of states (Anderson et al., 2016). To meet growing demand for agricultural foodstuffs and ecosystem service further expansion of plough-lands can’t be avoided. Estimation of compromises between social and ecological consequences and advantages of transformation of available land reserve into cultivated lands are crucial. In the former Soviet Union countries
(in European Russia, western Siberia, Ukraine and Kazakhstan), where the transition from state-command to market-driven economies resulted in widespread agricultural land abandonment, cropland expansion may incur relatively low costs, especially compared with tropical regions. Restoration of potentially available cropland in such regions may make a serious contribution to world cereals production with relatively low compromises with environment compared to the tropics, but it mustn’t be a panacea for solution of global food security problems or reduction of pressure of land tenure on tropical ecosystems (Meyfroic et al., 2016). It’s considered that main former members of Soviet Union, in particular, Kazakhstan, Russia and Ukraine (KRU-region) have the highest potential for increase of food supplies and food security strengthening in the world (Schmitz et al., 2015) and recently are becoming of key importance in establishment of world agricultural market (Liefert et al., 2010). It’s confirmed by restriction of grain export (bans, quotas, taxes) for KRU-region on both national and international levels, which resulted into a significant rise of prices on the world market. Influence of climate on production and risks of demonstrations of lean years for cereals also predetermine price policy inside countries of export and on the world market (Dronin et al., 2011). Repetition of scenario of temporary export restriction from KRU-region may seriously worsen the situation on the grain world markets in future, especially with unfavorable consequences for grain net importing countries. At the same time, results show that for a country like Ukraine, i.e., a country usually exporting large shares of its total grain production, the introduction of export restrictions could potentially result in decreases of domestic consumer prices to a level even below a situation with normal weather conditions (Fellmann et al., 2014). Interference of export and import on formation of price policy for agricultural products in Ukraine is shown in the work (Ivaniuk, 2014). T. Melnyk and O. Golovachova made a complex analysis of regulations of foreign trade in agriculture and integration of state-of-the-art experience of governmental support to increase management efficiency of agricultural production (Melnyk &Golovachova et al., 2015). Detailed examination of dynamics of agricultural price and trade interventions in Bulgaria, Poland, Romania, Russia, and Ukraine was examined in works (Agricultural support…, 2000; Pall et al., 2013; et al.).

Continuing climate fluctuation results into increasing uncertainties in yield for main consumer agricultural products. Authors (Bren D’Amour et al., 2016) find that the Middle East is most sensitive to connected supply shocks in wheat, Central America to supply shocks in maize, and Western Africa to supply shocks in rice. Weighing with poverty levels, Sub-Saharan Africa is
most affected. Altogether, a simultaneous 10% reduction in exports of wheat, rice, and maize would reduce caloric intake of 55 million people living in poverty by about 5%. Export bans in major producing regions would put up to 200 million people below the poverty line at risk, 90% of which live in Sub-Saharan Africa. Results suggest that a region-specific combination of national increases in agricultural productivity and diversification of trade partners and diets can effectively decrease future food security risks. For this reason, season climate forecasts are becoming the most important element in some decision making policy systems, particularly, in the context of adaptation to climate fluctuation, first of all, for agriculture (Troccoli, 2010). Results of climate forecasting, which are used in development of different adaptation variants in agriculture, should have an opportunity to influence decisions taken by interested parties so that to improve agricultural production results and to increase competitive positions on the world market. Agriculture adaptation variants can be developed with the help of forecasts of climate genetic properties on a number of time scales, from several days up to several decades against five headings: relevance, reliability, stakeholder engagement, holism and accuracy (Challinor, 2009). At present problems of climate fluctuation, possibility to develop situational models of forecasting climatic conditions are disclosed in a great deal of works, including possibility to improve quality of Gaussian models of forecasting various scenarios of cyclic climate fluctuation (Gershgorin et al., 2012), use of physics ensemble approach for regional climate forecasting (Liang et al., 2012), the possibility of using normalized difference vegetation index (NDVI), which is based on satellite data, using effective climatic signals and artificial neural network (ANN) for agricultural drought forecasting based (Marj et al., 2011), use of models of multivariate linear regression (MLR) or a standard linear state-space (LSS) approach for short-term temporary forecasting of seasonal fluctuations of temperature and precipitations (Kokic et al., 2010) etc. All over the world a lot of attention is paid to prediction of yield of agricultural crops, for this purpose many different methodological approaches based upon neural networks were developed, including for crop yield estimation from normalized difference vegetation index image time series (Bose et al., 2016), prediction of yield of agricultural crops depending on climate and soil variables (De Paepe et al., 2016), for space clustering and temporary prediction of wheat yield (Bijanzadeh et al., 2016; Pantazi et al., 2016), prediction of barley yield against total of 10563 data from 17 features (Mokarram et al., 2016), use of Water production functions (WPFs) for space-time modeling of yield from
irrigation that are useful tools for control of irrigation and economic analysis of yield decrease because of deficit of irrigation (Haghverdi et al., 2016) etc.

Water resources availability has a significant impact on agricultural land-use planning, especially in a water shortage area. The random nature of available water resources and other uncertainties in an agricultural system present risk for land-use planning and may lead to undesirable decisions or potential economic loss. Owing to this an inexact risk management model (IRM) was developed for supporting agricultural land-use planning and risk analysis under water shortage. The model ensures possibility to take decisions on risks minimization and assistance in search of the economically efficient strategy of agricultural land-use planning with complicated uncertainties (Li et al., 2016). Nevertheless, understanding of determination of space regularities of agricultural intensity and changes in them is restricted. In modern conditions sub-national variation of levels of agricultural intensity of cultivation of different groups of crops to a great extent depends on quality and potential of land fertility and less on labor productivity. So the challenge for policy formation on future land use is how to move from an unmanaged combination scenario towards a managed combination scenario, in which the soil functions are purposefully managed to meet current and future agronomic and environmental targets, through a targeted combination of intensification, expansion and land drainage. (Valujeva et al., 2016). Such purposeful space-time management requires grounding of particular efficiency conditions for land and water use by optimization of land fund structure proceeding from basin, position-dynamic and adaptive-landscape principles (Lisetskii et al., 2014, 2015; Pichura, 2015).

2. MAJOR GEOGRAPHICAL REGULARITIES OF LAND PRODUCTIVITY CHANGES OVER THE PAST 100 YEARS OF AGRICULTURAL DEVELOPMENT IN SOUTHERN UKRAINE

Objective difficulties in integration partial soil fertility indices for estimation of soil quality (SQ) determine a permanent interest to use of comparable fertility of agricultural crops, which collectively reflects efficient fertility of soils. An approach based upon comparative analysis of variation of dynamic yield rows of this crop depending on regional peculiarities of the territory, in fact is indicative A. A. Zhuchenko (Zhuchenko, 1990, p. 280) named it the summative agroecological regional assignment.
Idea of territorial differences in natural capacity of soils in Northern Black Sea region started forming in 19th century in the course of accumulation of data of agricultural crops yield within steady administrative and economic units (district country cottages and volosts, i.e., districts).

To estimate soil fertility for the last 100 years’ materials of the end of 19th century in the part of Black Sea region, where Kherson province was located, were used as comparative basis. This is the territory in – between the Dnieper and Dniester Rivers within the limits of southern part of forest-steppe, steppe and dry steppe landscape zones. The territory had an access to the Black Sea through ports Odessa, Nikolaev, Kherson. The steppes on Earth cover more than 6% of the land area and are one of the main biomes, accumulating energy resources in humus-rich Chernozems, which ruthless exploitation leads to a widespread degradation (Lisetskii et al., 2016). Kherson province was created in 1803 and its territory was being separated into counties up to 1835. As a result of military survey of 1850-1852 Kherson province comprised of six counties (Ananiev, Tiraspol, Odessa, Yelisavetgrad, Alexandria, Kherson) and covered land fund area of 7.19 mln. ha (for reference – this is larger than area of Ireland) which at that time was ploughed up by 45.4%. By the late 19th century due to ploughing up in Kherson province pastures area reduced from 80 (in the beginning of the century) to 20% (Lisetskii et al., 2010). According to our estimations presently (i.e., after 130 years of development) pastures area within comparable limits is 68.3%.

Peculiarity of nature of land regions having high soil fertility and profitability of pastures reflects results of agricultural activity analysis for 1900-1908, which was mapped in the work (Shif, 1925, p.25). Map “Estimation of level of soils effective fertility” based upon data of average many-years (1953-1962) cereals yield (ignoring expenses) holds an intermediate position among estimation maps of the end of 19th century and the last third of 20th century (Kuz’michov, 1970).

Appraisal of Ukrainian soils in 1970-1980th was made proceeding from many-years data of yield of agricultural crops and in 1993-1995by natural peculiarities of soils (content of humus and physical clay in ploughing horizon, depth of humus horizon, depth of location of gleyic horizon, agrophysical condition index). Nevertheless, obtained estimations of soils did not always meet their actual productivity level.

In statistical and economic reviews district country cottages or their groups were used territorial units. It shall be noted that on the contrary from many posterior administrative territorial unit’s advantages of district country cottages in geographical analysis was their relative uniformity by natural
conditions and comparable area (about 33,000 ha). By land tenure private landowner lands prevailed: in 1896 they made up 61.2% of the province land fund as peasant holdings covered only 38.8% (Statistical and economic review..., 1897). In Kherson province the majority of peasants (former state-owned serfs) received on average from 7.3 up to 10.6 ha of land each and landowners-owned peasants – 3.7 ha each.

In every land tenure (256 territorial units in total) yield rows of spring wheat in private landowners’ lands for 1892-1900 had been registered (Materials..., 1902). Selection of spring wheat yield registration on private landowners’ lands permits to reduce impact of land tenure area on its productivity. In sowing structure of the province spring wheat prevailed: in 1892-1902 it covered 40% of area with variations in counties from 35 up to 43%. Alongside with spring wheat high sensitivity to soil fertility factors this circumstance determines possibility of reflection of almost undistorted influence of natural conditions with insignificant effect of manmade means of plant cultivation intensification. Analysis of yield row showed that 1892, 1899, 1900 could be regarded as lean years, as territorial differences in productivity were characterized by the largest variability (variation coefficient reached up to 43-94%). The remaining five years were characterized by more favorable conditions by production process, at that they showed themselves as three- and two-years periods (1893-1895, 1897-1898). Herewith average yield in 256 land tenures in the most favorable year did not exceed 12c/ha.

Territories within the limits of former Kherson province conform to 50 administrative regions of Odessa, Kirovograd, Nikolaev, Kherson and Dnepropetrovsk regions. For analysis 15-years-long yield rows of spring wheat from 1971 until 1986 in section of selected districts were used. In these years share of spring wheat in sown areas structure increased up to 50%. Variation coefficient of yield data reflecting variability of space non-uniformity varies within 11-20%. Whereas by many-years data of experimental stations variation coefficient of spring wheat yield in regions with precipitations lower than 500 mm per year is within 21-39%.

Agroclimatic conditions of two mentioned chronological intervals can be compared by data of instrument observations. Materials from meteorological station in Odessa showed that in the period from 1894 until 1900 the average temperature rise was 0.1°C compared to the previous (1882-1893) cycle of the same century (with average temperature 9.5°C) and by moistening conditions the period of 1884-1899 was characterized by average annual amount of precipitations – 394 mm. Period from 1971 until 1986 was characterized by higher moistening (precipitations amount increased up to 448 mm per year, but
The development and current state of the agricultural sector...

Average annual temperature increased up to 10°C. Available estimations of reaction of cereals productivity (Kotljakov, Glazovskij, Nikolaeva, 1992) show that climatic fluctuations of such amplitude do not exceed the level of significant yield variations (±10% from average many-years one). It promotes more unambiguous interpretation of space regularities in distribution of soil fertility.

For relative estimation of lands productivity for $i$-th land tenure we used productivity index ($I_i$) showing the share of yield range averaged for period $m$ and realized in particular years:

$$ I_i = \frac{1}{m} \sum_{j=1}^{m} \frac{X_{ij} - X_{\min j}}{X_{\max j} - X_{\min j}}, $$

where $X_{ij}$ – is yield in the territory of $i$-th land tenure in $j$-th year; $X_{\max j}$, $X_{\min j}$ – are maximum and minimum yield of $j$-th year respectively. Formula (1) is one methods of standardization of characteristic that is widespread in statistics, has already been used in appraisal of soils (Saharov, Hamzin, 1965) and is preferred due to possibility of content-related interpretation of resulting standardized values.

Distribution of productivity index (in more convenient expression–$I_i \cdot 10^3$) over the territory allows to express space regularities of variation of efficient yield level. Analysis of paired correlation coefficients between space yield rows of spring wheat showed that space regularities in yield distribution were becoming most stable in dry years (1892, 1896, 1899, except for 1890) and years with average yield (1894 and 1897). With introduction of the threshold value of correlation coefficient – 0.53 the group of years (1893, 1895, 1897, 1898) was distinguished, when with sufficient precipitations amount effect of edaphic environmental factors on lands fertility was being revealed more actively; it results into absence of conjunctions between space yield rows. Using correlation – independent fruitful years the productivity indices were calculated, geographical regularities in distribution of which clearly reflected differences in efficient fertility level acquired for 100-130 years and in particular districts–for even longer period of land tenure of Black Sea region area (Figure 1). Twenty-versts – and an-inch map of Kherson province (1:840 000) of late 19th century with indication of county cottages and volosts was base material (Materials…, 1902). It’s expedient to compare the map “Average many-years profitability of field land of 1900-1908” (Shif, 1925, p.

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25), which was mapped against data of land lease prices at the beginning of 20 c., with these results.

For analysis of productivity agro-landscapes in second half of 19th century in precious data were found in records of annual yields of southern Russian German colonists. According to data published at the end of 19th century (Postnikov, 1891) materials for two adjacent volosts of Berdiansk country of Tavria province were used. Nowadays this territory conforms to Tokmak and Chernigov districts of Zaporozhye region, Ukraine. In respect of physics and geography this is Priazov lowland with 400-450 mm rainfall per year and dominating conventional minor humus-poor Chernozems and partially southern humus-poor forester Chernozems. At the end of 19th century in land tenure history of this territory there was a remarkable period of 1870-1879, when many sowings turned out to be on new lands – firstly ploughed virgin soil-due to lands active ploughing up. It permits to estimate losses of efficient fertility in extensive agriculture with minimum fertilization of fields (Table 1). Productivity of old-arable lands summarized by four kinds of cereals was lower than of the firstly ploughed lands by average yields by 19% and by maximum ones – by 21%. Sensitivity of particular agricultural crops to high exhaustion of soil fertility is shown the following row: barley > winter rye = spring wheat > oats. In 10 years after ploughing up virgin soil decrease in productivity by average and maximum yields was 6-7% only.

Consequently, in extensive agriculture average annual reduction rate of soil fertility is estimated to be 0.6-0.7%. Therefore, at the beginning of 20th century old-arable lands reclaimed at the beginning of 18th century and earlier could have reached its critical exhaustion level of soil fertility resources.

Apart from biological removal and yield, water soil erosion was a significant factor of soils degradation. If in these bioclimatic conditions soil formation rate is estimated to be 1-2 t/ha per year (Lisetskii, Stolba & Goleusov, 2016), after ploughing lands on slopes annual erosion losses increased from 0.45 up to 8 t/ha. With acceleration of soil degradation processes, climate fluctuation and under influence of socio-economic reasons it has become clear just recently that land tenure and water use problems shall be settled (Lisetskii et al., 2014) and ways for their settlement shall be offered (Yermolaev et al., 2015).

Earlier (Tjutjunnik, Korotkova, Nadol’naja, 1988) it was noted that particular physical and geographical regularities were reflected in distribution of spring wheat yield over regions and its time variability. With a favorable combination of meteorological factors, they are significantly leveled off. With an unfavorable combination of agroclimatic conditions the pattern of

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productivity space distribution is especially informative for non-correlated years, when soil fertility is shown most clearly. Proceeding from correlation table 1972, 1976, 1983, 1985, 1986 years turned out to be independent with average yield 24.9 (19.7–27.9) c/ha that is by 15% less than average yield for the last decade.

Figure 1. Estimation of efficient soil fertility level at the beginning of 20th century in Black Sea region (by spring wheat productivity index – $I_i \cdot 10^3$).

Paradoxical ness of the result consisting in non-correlativity of space yield rows favorable for fertility of years at the end of 19th century and unfavorable at the end of 20th century, in our opinion, can be explained as follows. At the beginning of agricultural period the territory under consideration was characterized by large zonal differences of potential fertility. For example, in the map of isohumic belts of south-western Russia (Nabokih, 1911, p. 119) humus content in soils from the south to the north was increasing from 2 up to 10%, but presently the range of conforming soils reduced from 2 down to 6%.
Initial genetic differences of ploughing horizon were substantially leveled off under the influence of general zonal soil degradation processes, on the one hand, and under the influence of manmade factors of land tenure intensification (treatment, fertility etc.), on the other hand. Therefore, at current stage of land tenure the previously existing large differences in potential fertility are displayed less clearly in years with favorable agroclimatic criteria. Besides, much more powerful root age of winter wheat compared to spring one in years with favorable climate can use fertility resources, moisture content of ploughing and lower horizons (up to 50-60% of necessity in soil moisture is to be filled up from the second and third meter layers) more efficiently.

Comparison of space distribution of efficient fertility in three chronological sections (beginning, middle and end of 20th century) allows distinguishing the following main peculiarities. Permanently highest productivity level in Black Sea region is marked at the boundary of forest-steppe and steppe areas, where at the beginning of the century typical and conventional Chernozems contained 7-10% of humus.

In distribution of soil fertility natural zonal-provincial regularities are most objectively displayed in estimation of lands according to data of 19th century. To the south from the isoline restricting soils with humus content less than 5% (Nabokih, 1911, p. 119), and approximately coinciding with the northern boundary of southern Chernozems, there are only around 10% of county cottages with productivity index exceeding the average level (above 385) – see Figure 1. Using generalized data from counties of Kherson province (The collection..., 1904) we calculated yield classes by three criteria: land productivity (yields of main cereals in 1892-1900), monetary price of land and rentals are an unambiguous evidence of excess of average province estimations (84-86 scores) in north-eastern part of the territory under consideration (Alexandria, Yelisavetgrad counties and northern part of Kherson province). Areas with the lowest values of productivity index (<215) are completely concentrated in the southern boundary of Steppe dry zone (under scheme of natural and agricultural regional assignment of Ukraine (1985)), i.e., within the limits of sub-zone of southern Chernozems. In general view this peculiarity is confirmed on the map of field land profitability (Shif, 1925). For 100 years of land tenure of southern Chernozems the most significant reduction of their productivity took place.
Table 1. Variation of productivity of argoeocystems in extensive agriculture (against records of annual yields of southern Russian German colonists in Berdiansk county (by: Postnikov, 1891)

<table>
<thead>
<tr>
<th>Periods*</th>
<th>Years</th>
<th>Yields crops, c/ha</th>
<th>Winter rye</th>
<th>Spring wheat</th>
<th>Barley</th>
<th>Oats</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>average</td>
<td>maximum</td>
<td>average</td>
<td>maximum</td>
</tr>
<tr>
<td>I</td>
<td>1840-1869</td>
<td>6.0</td>
<td>16.8</td>
<td>5.4</td>
<td>12.9</td>
<td>9.2</td>
</tr>
<tr>
<td>II</td>
<td>1870-1879</td>
<td>7.3</td>
<td>21.6</td>
<td>6.0</td>
<td>18.9</td>
<td>10.8</td>
</tr>
<tr>
<td>III</td>
<td>1880-1889</td>
<td>7.0</td>
<td>22.7</td>
<td>5.3</td>
<td>16.5</td>
<td>10.8</td>
</tr>
</tbody>
</table>

Comparison of efficient fertility levels by periods

|          | I by II | 82  | 78  | 90  | 68  | 85  | 91  | 69  | 80  |
|          | III by II | 96  | 105 | 88  | 87  | 100 | 91  | 91  | 90  |

* Periods: I – use of old-arable lands; II – ploughing up virgin soil; III – use of newly reclaimed lands.

At the end of 20th century high level of efficient productivity (I > 450) was typical for districts with irrigation amelioration (Ovidiopol, Beliaevka, Belozerka, Novovorontsovka), where 11-35% of arable lands were being irrigated at that time. If according to data of 1953-1962 lands of average quality (of yield class 59-66) were represented by the narrow band on the south of Black Sea region, irrigation development in 70th-80th changed regularities in efficient fertility distribution over the territory. Proceeding from the productivity index value the worst conditions for realization of potential fertility of soils were marked in districts of Odessa without irrigation (Velikomikhailovka, Razdelnaia, Ivanovka). Consequently, productivity of lands in south-western forest steppe and steppe of Black Sea region decreased most significantly.

Initial (before agricultural period) space in homogeneity of soil fertility conditioned by soil and geographical zoning determined naturally conditioned differentiation of soil fertility. As far as lands were being used for agricultural purpose and soil-degradation processes were being developed both leveling of differences in lands quality and fertility reduction at different rate depending on differences of primary fertility level took place. Complex comparable estimation of lands quality should become one of the most important improvement mechanisms in new economic conditions. It permits to assess added profit in agriculture arising in labor productivity with equivalent

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expenses on lands with highest fertility and to create an objective basis for establishment of the fair land tax.

3. TRENDS OF VARIATIONS OF MOISTENING CONDITIONS IN REGIONAL CLIMATIC SYSTEM FOR THE LAST CENTURY

Rational use of land resources and introduction of adaptive agrotechnologies in terms of changing climate is a guarantee of high stable yields and provision of competitive position of agricultural producers of regions of Eastern-European plain. For the last seventy years warming during 10 first months of the year in average by 2°C (from 10.4 up to 12.4°C), increase of precipitations amount by 90 mm (from 314 up to 404 mm) (Lisetskii, Pichura, 2016) is being observed.

In dry conditions of steppe zone a strong dependency of yield of agricultural crops from moistening conditions is observed. It’s confirmed by facts known from sources of literature before the beginning of regular meteorological observations (from the end of 19th century). During 19th century droughts in southern Ukraine were registered in 1833, 1834, 1840, 1847, 1848, 1862, 1873, 1874, 1882, dust devils – in 1824, 1848, 1876, 1885, 1886, 1891, 1892, 1898, 1899. At the end of 19th century, when reliable statistical data appeared, low yields were registered in 1880, 1885, 1886, 1889, 1891, 1892, 1896, 1899 and 1900. Average value of annual amounts of precipitations for the period of 1892-1900 made up 352 mm that was by 21.2% less than 447 mm (standard). In this period spring wheat yields of 5.0-5.8 c/ha were actually provided. Years with the most unfavorable climate in this period were actually 1894 and 1900 with precipitations amount 251.5 mm and 229.7 mm respectively. Decrease in annual amount of precipitations by 46 mm resulted into reduction of yield relative to average value for the period by 40-48% (by 1 c/ha).

When estimating influence of changes on conditions of lands productivity potential using data of three basic meteorological stations (MS) in the south of Eastern European plain (Odessa, Simferopol, Kherson) the trend-cyclic rise of annual amounts of precipitations was established from the end of 19th century until the beginning of 21st century in average by 0.9-1.7 mm per year and, consequently, for the last 130 years (Figure 2, 3) annual amount of precipitations in average increased by 117–221 mm. In 20th century – at the
beginning of 21st century the variation coefficient of annual amount of precipitations is estimated by values 25-28% (Table 2). With intensive progress in development of agricultural technologies since the end of 19th century until now it ensured increase of land productivity potential by 4.5 times.

From 1887 until 2014 two qualitative periods of orientation of changes of annual precipitations (Figure 4) were distinguished. Besides, there is no relationship between temperature variation and annual precipitations amount in century dynamics.
Figure 2. Dynamics of variation of precipitations (P, mm) in the south of Eastern European plain: a) MS Odessa, b) MS Simferopol, c) MS Kherson.

Figure 3. (Continued).

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Figure 3. Deviations of precipitations (P, mm) from norm within one century in 20th – at the beginning of 21st century by data of meteorological stations of south of Eastern European plain: a) MS Odessa, b) MS Simferopol, c) MS Kherson.

$T_{Odessa} = 1,36 \cdot t - 68,6, \ r = 0,37$;
$T_{Simferopol} = 1,71 \cdot t - 96,9, \ r = 0,47$;
$T_{Kherson} = 0,88 \cdot t - 37,6, \ r = 0,29$.
Table 2. Statistical characteristics of moistening conditions in the south of Eastern European plain in 20th – at the beginning of 21st century

<table>
<thead>
<tr>
<th>Indices</th>
<th>MS Odessa</th>
<th>MS Simferopol</th>
<th>MS Kherson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (norm)</td>
<td>399.8</td>
<td>446.9</td>
<td>399.7</td>
</tr>
<tr>
<td>Standard error</td>
<td>10.9</td>
<td>11.5</td>
<td>9.3</td>
</tr>
<tr>
<td>Median</td>
<td>395.0</td>
<td>444.6</td>
<td>380.0</td>
</tr>
<tr>
<td>Mode</td>
<td>402.0</td>
<td>Not found</td>
<td>334.0</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>106.5</td>
<td>123.9</td>
<td>99.7</td>
</tr>
<tr>
<td>Dispersion of sample</td>
<td>11332.3</td>
<td>15359.0</td>
<td>9942.1</td>
</tr>
<tr>
<td>Excess kurtosis</td>
<td>-0.5</td>
<td>-0.1</td>
<td>1.7</td>
</tr>
<tr>
<td>Asymmetry</td>
<td>0.3</td>
<td>0.4</td>
<td>0.8</td>
</tr>
<tr>
<td>Minimum</td>
<td>192.0</td>
<td>215.8</td>
<td>186.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>662.0</td>
<td>820.7</td>
<td>778.1</td>
</tr>
<tr>
<td>Reliability level (95.0%)</td>
<td>21.6</td>
<td>22.8</td>
<td>18.4</td>
</tr>
<tr>
<td>Variation</td>
<td>26.6</td>
<td>27.7</td>
<td>24.9</td>
</tr>
</tbody>
</table>

Figure 4. Coincident difference integral curves of precipitations (Pi) by data of meteorological stations in the south of Eastern European plain.

In the first period (end of 19th century – mid 20th century) average value of annual precipitations amount registered at meteorological stations was 375 ± 12 mm; scale of the value is estimated as 208 ± 8 ÷ 646 ± 32 mm with variation coefficient 24.7 ± 2.8%.

Starting from 1950 a steady tendency of moistening level rise was marked, average (using data from the same meteorological stations) value was 458 ± 23 mm of precipitations per year, scale of the value varied from 251 ± 26 up to

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754 ± 47 mm with variation coefficient 23.7 ± 1.7%. In the second period (1950-2014) moistening increased in average by 1.22 times. In the second period the frequency of probability of display of years exceeding the century norm of precipitations increased twice – from 0.32 up to 0.66 (Figure 3).

4. **Estimation of Influence of Climatic Dynamics on Bioproductivity**

In virgin steppes with dominating steppe cereals (*Stipa, Festuca*) with variation coefficient of annual precipitations amount from 17 up to 27% the fluctuations of productivity of aerial phytomass in comparable periods were 19-23% (Table 3).

**Table 3. Scale of values and variation coefficients of productivity of virgin steppe and yields of agricultural crops in 19th–20th centuries**

<table>
<thead>
<tr>
<th>Location</th>
<th>Vegetation, agricultural crops</th>
<th>Years of registration</th>
<th>Phytomass/yields, c/ha</th>
<th>V, %</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>average</td>
<td>max</td>
<td>min</td>
</tr>
<tr>
<td>Priazovie</td>
<td>Goldilocks-sheep fescue-feather grass association</td>
<td>1967-1970</td>
<td>36.6</td>
<td>44.6</td>
<td>28.1</td>
</tr>
<tr>
<td>Nikolaev region, Nikolaev district</td>
<td>Sheep fescue-feather grass association</td>
<td>1981-1986</td>
<td>46.7</td>
<td>62.3</td>
<td>36.7</td>
</tr>
<tr>
<td>Odessa county (modern Nikolaev district of Nikolaev region)</td>
<td>Spring wheat</td>
<td>1892-1900</td>
<td>5.0</td>
<td>11.2</td>
<td>0</td>
</tr>
</tbody>
</table>

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Table 3. (Continued)

<table>
<thead>
<tr>
<th>Location</th>
<th>Vegetation, agricultural crops</th>
<th>Years of registration</th>
<th>Phytomass/yields, c/ha</th>
<th>V, %</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>average</td>
<td>max</td>
<td>min</td>
<td></td>
</tr>
<tr>
<td>Odessa county (modern Ochakov district of Nikolaev region)</td>
<td>The same</td>
<td>1892-1900</td>
<td>5.8</td>
<td>12.7</td>
<td>0</td>
</tr>
<tr>
<td>Kherson province, Falz-Fein’s estate (modern Velikoaleksan drovka district of Kherson region)</td>
<td>Winter rye</td>
<td>1880-1886</td>
<td>6.4</td>
<td>11.3</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>Winter wheat</td>
<td>1881-1886</td>
<td>5.0</td>
<td>9.4</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Spring wheat</td>
<td>1880-1886</td>
<td>4.0</td>
<td>7.6</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Barley</td>
<td>1880-1886</td>
<td>7.1</td>
<td>13.3</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Millet</td>
<td>1880-81, 1883-86</td>
<td>3.7</td>
<td>9.4</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Oats</td>
<td>1881-1886</td>
<td>5.2</td>
<td>7.2</td>
<td>3.7</td>
</tr>
<tr>
<td>Kherson province, Apostolovo country cottage (modern Apostolovo district of Dnepropetrovsk region)</td>
<td>Winter rye</td>
<td>1877-1886</td>
<td>4.1</td>
<td>5.6</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>Spring wheat</td>
<td>1877-1886</td>
<td>3.0</td>
<td>5.2</td>
<td>1.5</td>
</tr>
<tr>
<td>Kherson county</td>
<td>Millet</td>
<td>1877-1886</td>
<td>5.8</td>
<td>9.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Berdiansk county (modern Zaporozhye region), 8 farms of German colonists</td>
<td>Spring wheat</td>
<td>1860-1889</td>
<td>5.9</td>
<td>12.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Location</td>
<td>Vegetation, agricultural crops</td>
<td>Years of registration</td>
<td>Phytomass/yields, c/ha</td>
<td>V, %</td>
<td>Data source</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>--------------------------------</td>
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<td>------------------------</td>
<td>------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>average</td>
<td>max</td>
<td>min</td>
</tr>
<tr>
<td>The Crimea</td>
<td>Winter wheat</td>
<td>1900-1921</td>
<td>7.0</td>
<td>12.2</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>The same</td>
<td>1900-1920</td>
<td>7.3</td>
<td>3.8</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td>Barley</td>
<td>The same</td>
<td>5.7</td>
<td>10.0</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Oats</td>
<td>The same</td>
<td>6.0</td>
<td>10.3</td>
<td>0.6</td>
</tr>
<tr>
<td>Nikolaev region</td>
<td>Winter wheat, rarity plots</td>
<td>1975-1984</td>
<td>39.5</td>
<td>51.2</td>
<td>23.7</td>
</tr>
<tr>
<td>Odessa region</td>
<td>The same</td>
<td>The same</td>
<td>37.4</td>
<td>49.6</td>
<td>27.1</td>
</tr>
<tr>
<td>Kherson region</td>
<td>The same</td>
<td>The same</td>
<td>33.8</td>
<td>47.9</td>
<td>19.5</td>
</tr>
<tr>
<td>Nikolaev region</td>
<td>Winter wheat, in irrigated</td>
<td>The same</td>
<td>41.7</td>
<td>51.2</td>
<td>29.7</td>
</tr>
<tr>
<td>Odessa region</td>
<td>The same</td>
<td>The same</td>
<td>35.8</td>
<td>46.4</td>
<td>24.5</td>
</tr>
<tr>
<td>Kherson region</td>
<td>The same</td>
<td>The same</td>
<td>33.6</td>
<td>18.3</td>
<td>47.0</td>
</tr>
<tr>
<td>Nikolaev region</td>
<td>Winter wheat, irrigation</td>
<td>1977-1984</td>
<td>45.3</td>
<td>51.3</td>
<td>40.1</td>
</tr>
<tr>
<td>Odessa region</td>
<td>The same</td>
<td>1976-1984</td>
<td>47.8</td>
<td>55.1</td>
<td>40.8</td>
</tr>
<tr>
<td>Kherson region</td>
<td>The same</td>
<td>The same</td>
<td>44.1</td>
<td>55.3</td>
<td>27.2</td>
</tr>
<tr>
<td>Kherson region</td>
<td>The same</td>
<td>1990-2000</td>
<td>27.4</td>
<td>37.2</td>
<td>17.0</td>
</tr>
<tr>
<td>Kherson region</td>
<td>The same</td>
<td>2001-2014</td>
<td>25.7</td>
<td>34.8</td>
<td>15.8</td>
</tr>
<tr>
<td>Kherson region</td>
<td>Winter wheat, irrigation</td>
<td>1990-2000</td>
<td>38.8</td>
<td>51.8</td>
<td>28.4</td>
</tr>
<tr>
<td>Kherson region</td>
<td>The same</td>
<td>2001-2014</td>
<td>38.2</td>
<td>47.5</td>
<td>28.1</td>
</tr>
</tbody>
</table>
Investigations of agroclimatologists (Zhuchenko, 1990) have shown that with rise of efficiency in agriculture and, consequently, yield dependence of the latter from climate and weather increases. Nevertheless, in this case this is not about reduction of absolute yield value (because possibility of provision of basic yield minimum due to scientific and technical progress), but about rise of dependence of yield relative variability from uncontrollable variations of external medium parameters and, first of all, weather fluctuations. At that the latter has the largest impact on high yield cultivars and hybrids of plants, which most of all depend on optimization of all factors of external medium.

Analysis of dependence of productivity from climatic conditions (provision of heat and moisture – by (Volobuev, 1975)) with higher level of agriculture development is reduced (Figure 5).

\[
Y = 6.28 \cdot \exp(4.3 \cdot 10^{-3} Q) - 261.1 \cdot \exp(-9.4 \cdot 10^{-3} Q), \ r = 0.61
\]

Figure 5. (Continued).
In the second half of 19th century in usual farmsteads average variation of yields of six cereals was 56% and with higher efficiency in agriculture (of German colonists) it was 42%. Author’s processing of yield row for the period 1886-1925 in Askania-Nova (Kovarsky, 1930) showed that using variation

\[ Y = 30.7 - 219 \cdot Q^{-0.67}, \quad r = 0.15 \]

Figure 5. Dynamics (a, b) and dependence (c, d) of spring wheat yield from energy of climatic expenditures (Q, MJ/m²) in the territory of Eastern European plain in various periods of agricultural development: a, b) 1900-1921; c, d) 1971-2014.
coefficients (indicated in brackets) the following ranked row of yields stability by crops: winter rye (50) < spring barley (54) < winter wheat = spring wheat (67). Influence of agrotechnical measures significantly changes productivity stability. Thus, according to the same data after introduction of clean tillage (1905-1925) compared to the previous period the variation coefficient by particular kinds of crops reduced by 12-39%. Consequently, at the beginning of 20th century agrotechnical achievements determined reduction of variation in yield of cereals (by for kinds) down to 38%. Role of rear experimental events is of large importance: such variation coefficient by winter wheat yield for the period 1900-1920 compared to the previous period, including dry lean 1921, was less by 6.5%. In 1921 minimum amounts of precipitations were marked on the large territory (for instance, that year there was only 230 mm of precipitations (58% of norm) in Odessa).

As it is shown in Figure 5, low level of use of agrotechnologies in 1900-1921 was reflected in rather high closeness of relationship (r=0.61) of yield variation (Y, c/ha) of the main most widespread crop (spring wheat) from energy climatic expenses (Q, MJ/m²), which are determined by humidity (precipitations) and sun radiation (Volobuev, 1975). In modern conditions reduction of climatic influence by 4 times (r=0.15) on formation of yield of agricultural crops is conditioned by high technological vector of agricultural development that resulted into stability of productivity.

For comparison of stability index of agricultural productivity, which is expressed in yield of crops by two time sections the formula offered by I.B. Zagaitov and P.D. Polovinkin (1984) is used (by: Pykhtin, Veklenko, 1988):

\[ V_c' = 1 - \frac{\sum_{i=1}^{n} |P_i - \bar{P}|}{\sum_{i=1}^{n} P_i} \]  

(2)

where \( V_c' \) - is stability index changing from 0 to 1; \( P_i \) - is actual productivity; \( \bar{P} \) - is average productivity for time t; \( \sum_{i=1}^{n} \) - is amount of deviations by module.
Value of temporary stability of agricultural productivity in 1860-1921 was 0.60, in 1971-2014 – 0.84. Space variability of stability in 1860-1921 was from 0.43 up to 0.83, in 1971-2014 – 0.5-0.2. Introduction of innovative agrotechnologies ensured rise of space-time productivity of agriculture for the last 150 years by 1.3-1.8 times causing yield rise in average by 4.5 times (from 6.0 up to 27.7 c/ha) (Table 4) and stabilization of agroproduction process by approximately 2.2 times (variation reduction from 43 down to 20%).

No uniform redistribution and deficit of annual climatic energy in the period of vegetation of agricultural crops in steppe and dry steppe zones of the south of Eastern European plain are significantly compensated by application of irrigation amelioration. Thus, in the second half of 20th century on in irrigated lands both in large land tenures and state crop testing sites yields of winter wheat were changing with the course of years with variation coefficient (V) 22% (i.e., variation still remains strong). In particular, 4 years (1975, 1976, 1979 and 1983) were characterized by severe droughts in the south of Ukraine (Heat resistance …, 1985). At the same time in agro-ecosystems of steppe zone with irrigation amelioration value V by winter wheat yield was the lowest – 16% (average variation).

From the beginning of irrigation functioning conditions of all components of natural environment changed, in particular, orientation and rates of soil processes changed (Lisetskii, Pichura, 2016a). Results of these changes may have either positive (improvement of water supply, productivity rise etc.) and negative effect (underflooding, salinization, alkalinity, bogging-up processes).
Orientation and intensity of negative phenomena on agricultural and adjacent lands depend, first of all, on climatic and hydrological conditions of the region, volumes of irrigation water supply. Constant under flooding of agricultural territories in the south of Eastern European plain caused by natural (precipitations) and anthropological factors (construction of cascade of water basins on the Dnieper and hydrotechnical irrigation systems) results into large economic losses of agricultural and industrial complex. Excessive moistening and under flooding of territories cause reduction of yield of agricultural crops down to 60%, in some cases, complete demolition. For scientific grounding of preventive measures of such situations it’s expedient to apply modern complex approaches and non-linear methods of space-time simulation and forecasting on basis of GIS and neurotechnologies (Pichura et al., 2015; Lisetskii et al., 2015). The method of creation of forecasting estimation system of probability of net profit losses from shortage of yield caused by underflood of agricultural territories against Markov’s discrete purpose (Zadorozhnyy, 2012).

Development and support of irrigation in steppe and dry steppe zones of the south of Eastern European plain are a guarantee of preservation of tendency for getting stably high yields and provision of competitive positions of separate agricultural producers and countries as a whole. At present irrigation allowed getting yield of agricultural crops 1.45 times higher than yield of rain crops. i.e., profit on irrigated lands is increased in average by USD 1800/ha.

Territorial peculiarities of distribution agricultural industrial potential in Ukraine in 1990-2009 are shown in Figure 6.

Figure 6. (Continued).
Figure 6. Average yield value of main export agricultural crops (c/ha) in Ukrainian regions (1990-2009): a) wheat; b) sunflower; c) soy; d) vegetables.
Agricultural industrial complex is the largest export industry in Ukraine. Foreign trade of AIC enterprises, which includes export of grain (plant growing products), food products and sunflower oil in 2014 brought to state budget 16.6 bln. USD, which placed this industry in the first place, having advanced metallurgy (15.2 bln. USD) for the first time in 25 years.

5. **HISTORICAL VIEW ON FORMATION OF GRAIN MARKET IN 19TH – 20TH CENTURIES IN THE SOUTH OF UKRAINE**

Retrospective view on formation of free market for southern edge of Russia in the second half of 10th – beginning of 20th century is remarkable in the part of market relations related to entry to the world market for grain export. Exactly this product attracted attention of foreign entrepreneurs in southern ports of the Black Sea. In this period in Odessa there were 8 consulates general and 12 consulates, in Nikolaev – 12 consulates, vice Consuls and consulate agents, which represented interests of Greek, Turkish, German, Netherlands, Belgian, Danish, Serbian, British, Portugal, Sweden-Norwegian, Brazilian, Italian, French and Austro-Hungarian capital. This system of public labor distribution southern regions became the largest suppliers of grain and other agricultural products. Construction of port and bread quay in Odessa was started at the beginning of 19th century, when in 1802 above 100 big ships with Russian bread arrived in Odessa. Nikolaev and Kherson as ports remained closed for foreign ships until 1862. But under effect of the world market their commercial ports were opened. In those times Russia did not have a commercial fleet and its foreign trade was realized by foreign ship and insurance companies, which allowed them to deliver from southern ports not only grain, but hundreds millions of golden rubles as profit. Great Britain was the main market outlet of grain. From Black Sea ports products were delivered to Germany, France, Holland, Belgium, Switzerland, Italy, Greece, Spain, Portugal, Austro-Hungary and Denmark.

Supremacy of foreign market over agricultural production of the south was obvious that was acknowledged in Russian official circles. Historical reliability of importance of southern Black Sea ports in grain export in the south of Ukraine is confirmed by statistical reports, statistical and economic reviews of Kherson province, reports of mayors of Odessa, Nikolaev, Kherson, statistics of grain export (Figure 7).
At the end of 19th century several railway lines were built, which allowed to deliver bread from remote regions. At the end of 19th century Odessa was on the first place by bread trade turnover in Russia: rarely less than 1600 mln. t of bread per year was delivered from Kherson, Podol, Volyn, Kiev, Ekaterinoslav and Tavria provinces. Bread export brought up to 150 mln. rubles per year. As of 1898 bread supply ratio of three ports was as follows: in Odessa – 54%, in Nikolaev – 30%, in Sevastopol – 16%. This ratio was certainly changing with the course of time, but Odessa saved its leading position (Figure 7). Products were delivered not only from steppe provinces of Ukraine, but from Bessarabia, Don, Pre-Caucasian regions, although their share in export from south of Russia was insignificant.

Growth of demand for bread stimulated development of commercial crops framing in the south. But at that period Russian rivals, first of all, American exporters strengthened their positions on the world bread market. They were supplying bread to European countries and pushing Russian product out of it. The situation was worsened by the beginning of crisis of overproduction in agriculture in 1884. Therefore, when struggling for sales markets foreign merchants sold bread from Russian southern ports at exceptionally low prices, frequently promoting further reduction of prices on the world market. In spite of grain price reduction in the world and domestic markets commercial crops farming dominated in southern steppes of Ukraine. At the end of 19th century
bread export widened and remained an important source of capital at the beginning of 20th century (Figure 8).

Foreign trade relations of southern steppe grain producers started narrowing under the influence of some factors. First of all, these were droughts, negative impact of one-crop farming, economic fall and defeat in competitive struggle with American exporters on the world market.

Figure 8. Variation (a) and average (b) share value of export of bread products in 1909-1914 from port in Nikolaev.
6. **WORLD TENDENCIES OF CEREALS EXPORT**

Foreign trade operations with grain in the ancient world were characterized by low activity and irregularity. The main buyers were the ancient Greece and Rome, and grains were exported by Sicily and North Africa. The early middle Ages were characterized by mostly natural farms almost to the early mercantilism in the 15th–17th century. The most active phase of foreign trade relations was the period of late mercantilism, when the key stakeholders were represented by England, France, Spain and Italy. In the manufacturing period of capitalist development major exporter of grain were Russia, Poland, and importers were Britain, France, Spain, Portugal; the Netherlands (Amsterdam) conducted intermediary trade. Europe acted the main center of trade relations, including the “grain trade.” At the end of the 18th century, the world’s grain export was 0.75 million tons, i.e., 200 times less as compared to the current indicator.

The historical background of trade activation in the middle of the 19th century was the rapid development of industry, urban population growth and bread commercial production, creation and improvement of mechanized warehouses–grain elevators. The main importers of grain were the Western European countries, and the leader among them was the United Kingdom. This period was characterized by emergence of new expert regions of extensive bread production – the Danube countries, the United States, Canada, Argentina, Australia (Galushko et al, 2011).

The lack of food, especially grain products which even in the 19th century accounted for about a half of the daily diet (Brodel,’ 1995), was one of the characteristic phenomena of the European history up till the middle of the 19th century. Lean years led to social upheavals in the country and society. As pointed out by known researcher F. Brodel,’ for many centuries in Europe, hunger “returned with such persistence that became a part of the biological regime” (Brodel,’ 1995, s.89). The so-called “Little Ice Age” that lasted for 14th-19th century played a significant role in the creation of unfavorable economic conditions. At this time, hungry years became typical for Europe – in the 16th – 19th century only in France hunger occurred 40 times across the whole country.

An important factor in the development of foreign trade and trade in grain, in particular, was that the traditional grain sources for Europe (Greece, Thrace, Egypt) till the 16th century fully ceded to the Ottoman Empire, and open lands in the New World were not yet developed. At this time food started being exported from the northern and eastern edge of Europe, and not least, the
Polish–Lithuanian Commonwealth, which, having low yields, shipped for export almost all locally grown wheat that was highly valued in European countries. During this period, the economic relations of the Polish state with Ukraine and its development by the Polish gentry, which, according to researchers, played a significant role in further spiritual and political influence of Poland on the Ukrainian territory, were being formed (Brodel,' 1995).

The first report on the fertile land then belonging to the Polish state was made by Polish historian and chronicler Maciejz Miechowa. In “Treatise on the Two Sarmatia” (1517) he pointed out, describing the territory of modern Ukraine, that there the land was “the most fertile in Europe and had the mildest climate” (Mehovskyy, 1936, s. 36). This phrase was almost literally repeated one hundred and eighty years later by French author Gaspard de Tandy, who served in the Polish court (Hauteville, 1697). Despite the lack of information and imperfect mechanisms of transmission, this statement started spreading and was becoming frequently mentioned in travel notes, official reports, etc. Thus, participant of the campaign of Charles XII at Poltava, priest Johann Bardo wrote about the great crops of wheat in Ukraine, so it would be more than enough to produce bread and alcoholic beverages (Bardili, 1730). Reports by French agents in 1771 and 1784 without specifying sources of information indicated “huge, as at home, piles of rotting wheat, which could feed the whole of Europe” and such cheapness of wheat so locals refused to grow it (Brodel,’ 1995). By the end of the 18th century, the idea of the incredible productivity of Ukraine became an axiom and was reflected even in researches (Kirilov, 2014). The rapid growth in export volumes was observed in the late 50-ies of the 20th century, and in 1973-1975s it reached 160 million tons, or over 11% of the world production. Along with the growth of export, its composition changed as well—some countries with intensive development of livestock increased imports of feed grains (Denmark, the Netherlands, Japan), countries with high population growth significantly increased the demand for food grains (Sri-Lanka), exports were also increased by countries that suffered from crop failure (Galushko et al., 2011).

Now, the world grain market is the largest, being characterized by a number of price and non-price barriers to enter it. In the overall balance of international trade, grain is ranked third in terms of transportation volumes after coal and oil, but in terms of value it is ranked first. The level of marketability and grain production volumes for export are different—the largest share of exports belongs to wheat, and the lowest share belongs to rice, millet and sorghum. In recent years, there has been increasing competition in the grain market. In this regard, a government policy in many countries is to

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overcome dependence on imports and stimulate the growth of grain production by providing subsidies and preferences for commodity producers. The grain market is characterized by its dynamism and rapid growth of supply. So, the priority for sales today was Asian and African countries. The main feature of the modern world grain market is that production is growing slower than consumption. In recent years, grain shortage in the market had been offset by reserves. This situation has provoked increased prices for grains. Given the fact that grains are the basic food for the population and a major feed ingredient in livestock farming, we can say that the world is facing a food crisis that has become systemic. The continuous growth of the world population, in average by 1.2 percent a year and global changes in the consumption of animal products definitely require increased production of grains in the world.

Today, the main grain exporters in the world market are: The United States, Canada, Australia, Argentina, EU, Ukraine, Russia, which provides about 90% of its turnover (Table 5).

The United States produces more than a half of the world’s grain exports. The leading exporters include 20-25 countries; the rest produces grain products mainly for their own use or import. Ukraine in 2014 took third place (16.7% of the world market) in exports of barley, fourth (6%) in exports of corn and sixth (5.4%) in terms exports of wheat. The major exporters in the wheat market are the United States (23%), Australia and EU (15% each), Canada (14%) and Argentina (9%). The Americas continue to hold the leadership in grain exports, its share in the world’s exports is 51.2%. In the grain 2013-2014 seasons, according to the Global Grain Market Report of the USDA National Agricultural Statistics Service, the largest volumes of grain were exported by the United States, i.e., 72.3 million tons, of which wheat accounts for 35 million tons, the second place is taken by the European Union (28 countries), i.e., 38.5 million tons of grains, of which wheat accounts for 30.5 million tons, Ukraine takes the third place – 32.3 and 23 million tons, the fourth place is taken by Canada–28 and 22 million tons respectively. The fifth and sixth places are shared by Australia and Russia with the wheat export volumes of 18.5 million tons. Asian countries have increased its export potential by 7.2 times; their share in the global grain market is 16%. Europe increased grain exports by 3.1 times; its niche in the global grain market is 26.6%, it takes the 3 place in the world in terms of grain exports. The North American countries exported 122.7 million tons, increasing its grain exports by 2.2 times, they take the second place, their share in world exports of corn is 37.5%.
Table 5. World grain exports, mil. t

<table>
<thead>
<tr>
<th>Marketing years</th>
<th>Countries</th>
<th>US</th>
<th>Argentina</th>
<th>Australia</th>
<th>Ukraine</th>
<th>Canada</th>
<th>EU</th>
<th>Russia</th>
<th>Brazil</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013/2014</td>
<td>72.3</td>
<td>24.50</td>
<td>21.90</td>
<td>32.30</td>
<td>28.00</td>
<td>38.50</td>
<td>26.10</td>
<td>20.10</td>
<td></td>
</tr>
<tr>
<td>2014/2015</td>
<td>80.4</td>
<td>27.60</td>
<td>24.40</td>
<td>33.58</td>
<td>28.2</td>
<td>53.50</td>
<td>30.70</td>
<td>21.00</td>
<td></td>
</tr>
<tr>
<td>2015/2016</td>
<td>84.5</td>
<td>35.90</td>
<td>23.80</td>
<td>37.40</td>
<td>27.60</td>
<td>52.10</td>
<td>34.70</td>
<td>34.40</td>
<td></td>
</tr>
<tr>
<td>2015 in% to 2013</td>
<td>116.87</td>
<td>146.53</td>
<td>108.68</td>
<td>115.79</td>
<td>98.57</td>
<td>135.32</td>
<td>132.95</td>
<td>171.14</td>
<td></td>
</tr>
</tbody>
</table>

Source: formed according to data of the International Grains Council.

South American countries are actively involved in the competition for their niche in the global grain market, they have increased grain exports by 3.6 times and their share in the world exports of grain is 13% compared to only 5% in 1995. For 37 years, Oceania has increased grain exports by 8.7 million tons, or by 2 times. Although least developed countries have increased grain production over the years, but their exports have remained at the same level, they only meet domestic needs. Among the world’s country, the United States is the largest grain exporter–99.9 million tons, having the 30.5% share in the world’s exports of grain and almost the 60% share in the regional market. The United States are constantly increasing their export capacities; for 37 years they have increased grain exports by 2.5 times. Over these years, Argentina alone has overtaken the United States and increased its grain export potential by 2.7 times and has come second in the quantitative export of grain and ahead of France. In the 2016-2017 marketing year (MY), an increase in the world’s grain production is anticipated. According to USDA forecasts, the world production of grains of all kinds will reach 2.6 billion tons, which is 4% higher than in the previous MY. Thus, wheat yield is expected to increase by 1.2%, feed grain yield is expected to grow by 6%, rice yield is estimated to gain another 2%.

According to forecasts of US experts, the total grain exports will amount to 383.6 million tons, i.e., 7.2 million tons less than in the previous season. However, the world grain stocks will grow. At the end of MY 2016-2017, they will reach 622 million, which is 4% higher than in the previous year.

The influence of the Black Sea region is growing in the world wheat trade. For two seasons in a row, Russia, Ukraine and Kazakhstan have sold in the foreign markets unprecedented volumes of wheat, which exceed the sales of the top exporting country like the United States and EU. According to results of the 2013/2014 grain season, wheat supply of these countries in world markets accounted for almost a third of the global sales volume of this type of
grain. The world grain imports increased by 2.7 times and in 2014 they reached 306.4 million tons. The main importers of grain are Asian countries. In 2007, they bought 119.2 million tons of grain, this is by 28.7%, more than in 1990; their share in the world import of grains is 38.9%.

For 37 years, Africa increased its grain imports by 8.2 times. Imports of the least developed countries have increased over this period by 4.9 times. Due to natural disasters, Oceania countries increased grain imports by 4.9 times. Countries in Africa, Asia and South America tend to import food grains. Large grain imports into developing countries are caused by two main reasons: some countries are economically and organizationally weak to increase its grain production in the modern large natural population growth and the need to overcome low living standards and poor nutrition; the second group is characterized by a significant proportion of effort and money put into agriculture for the production of export crops, the sale of which in the foreign market provides means to import food (Sri-Lanka, Indonesia, Philippines, etc.). The rest of the continent and industrialized countries have mostly increased its import of feed grains.

The world’s main grain importer is Japan. In the 1990-2000s, it was constantly buying 27 million tons of grain in the world market, and in 2007 it imported 25.5 million tons, showing decrease by 5.6%. Japan’s share in the world import of grain is about 10%. The second place in the import of grain is taken by Mexico, taking over China’s position. China is gradually reducing grain imports; over 50% of grain imports in China were accounted for food grains. South Korea and Spain in 2007 imported more than 12 million tons of grain. Spain, Malaysia increased grain imports by 6 times, Algeria experienced a 20-time increase. Feed grains account for more than a half of imports of the Netherlands.

The bread balance is an important economic factor for many countries. The passive balance characterizes the country dependence on imports and points to the need to establish additional feed grain supplies or increase the volume of its own grain production. The reasons for this situation are an imperfect structure of the country’s commodity production, intensification of livestock production, grain supply and demand imbalance. In some countries, passive balance of grain is offset by export of animal products. Although the value of exports offset grain passive balance, these countries cannot be equated to the previous group because:
a. The export of agricultural products and export operations in most of these countries is in the hands of the foreign capital returning not the entire cost of exported products to the country;

b. Countries from the previous group export not raw materials, but finished products—butter, cheese and the like, and the developing countries mainly export raw materials or semi-finished products, since prices are much lower.

In some agricultural countries the main cause of grain passive balance is a general inhibition of agriculture development due to imperfection of agricultural relationships, low introduction of product innovation and investment in the agricultural sector and other social and economic conditions.

The factors that influenced the grain market, include the following: reduction in world production and carry-over stocks of grain; reduction in wheat production in the United States, in India; need for large-scale imports; drought in Australia, a massive use of grains in bioethanol production; significant increase in corn consumption in China and exit of this country from the export market; reduction in corn production in Argentina and natural export offer reduction; tense world balance of barley; insufficient supply of malting barley in the EU countries; increase in freight rates; EUR strengthening; fluctuations of quotes in the energy market; large speculative transactions of investment funds on commodity exchanges; attempts to reform the export systems of Australia and Canada; regulatory policies of the European Commission in the grain market. During 2007/2008 MY the factors determining the grain market were as follows: adverse weather conditions in Europe; decline in grain production in Canada; unprecedented reduction in the world stocks of wheat; Ukraine’s withdrawal from the export wheat and barley market; new drought in Australia; adverse weather conditions in Argentina; introduction of duties on grain exports from Russia; adverse weather conditions in the winter wheat growing regions in the United States; huge need for grain imports to South–East Asia, Middle East, North America, India. As a result, the markets experienced an incredible increase in prices and quotations for wheat, barley, corn.

7. WORLD TRADE IN WHEAT

Today almost 20% of the world’s wheat harvest is in the international market. Major exporters that determine the state of the world wheat market is
Argentina, Australia, Canada, EU, Kazakhstan, Russia, Ukraine and the United States. According to the U.S. Department of Agriculture total wheat export offers from major exporters in MY 2015/2016 accounted for 88.7% of the total world trade, while in the last season the figure was 87.4% (Table 6, Figure 9).

According to the results of 2013/2014 MY, the world grain production has reached its historic high. In particular, compared to previous years, world production of wheat has risen to 715.1 million tons, or 8.4%, feed grains have reached 1306.7 million tons, or increased by 13.0%, and rice has constituted 496.9 million tons, or increased by 1.2%.

According to the Food and Agriculture Organization of the United Nations, there are countries in which the state of food insecurity is at a very low level, including Syria, Yemen and South Sudan. Overall, 33 countries, including 26 African countries, need external food aid.

World imports of wheat for the period have increased by 2.4 times (Table 7).

Table 6. World Wheat Exports, mil. t

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>5.255</td>
<td>7.742</td>
<td>11.951</td>
<td>7.450</td>
<td>1.800</td>
<td>6.500</td>
<td>4.3</td>
</tr>
<tr>
<td>Australia</td>
<td>13.764</td>
<td>18.455</td>
<td>23.031</td>
<td>21.269</td>
<td>18.00</td>
<td>19.00</td>
<td>12.5</td>
</tr>
<tr>
<td>Canada</td>
<td>18.992</td>
<td>16.768</td>
<td>17.603</td>
<td>18.581</td>
<td>21.50</td>
<td>21.00</td>
<td>13.9</td>
</tr>
<tr>
<td>European Union</td>
<td>22.279</td>
<td>23.086</td>
<td>16.691</td>
<td>22.621</td>
<td>30.00</td>
<td>27.50</td>
<td>18.1</td>
</tr>
<tr>
<td>India</td>
<td>0.060</td>
<td>0.073</td>
<td>1.0723</td>
<td>8.651</td>
<td>5.00</td>
<td>2.50</td>
<td>1.6</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>7.871</td>
<td>5.519</td>
<td>11.069</td>
<td>6.801</td>
<td>8.00</td>
<td>7.00</td>
<td>4.6</td>
</tr>
<tr>
<td>Russia</td>
<td>18.556</td>
<td>3.983</td>
<td>21.627</td>
<td>11.289</td>
<td>18.20</td>
<td>19.00</td>
<td>12.5</td>
</tr>
<tr>
<td>Turkey</td>
<td>4.363</td>
<td>2.944</td>
<td>3.678</td>
<td>3.583</td>
<td>4.00</td>
<td>3.20</td>
<td>2.1</td>
</tr>
<tr>
<td>Ukraine</td>
<td>9.337</td>
<td>4.302</td>
<td>5.436</td>
<td>7.190</td>
<td>9.50</td>
<td>8.50</td>
<td>5.6</td>
</tr>
<tr>
<td>Uruguay</td>
<td>1.039</td>
<td>1.612</td>
<td>1.78</td>
<td>0.811</td>
<td>1.20</td>
<td>1.50</td>
<td>1.0</td>
</tr>
<tr>
<td>USA</td>
<td>24.143</td>
<td>36.046</td>
<td>28.142</td>
<td>27.695</td>
<td>31.50</td>
<td>26.00</td>
<td>17.2</td>
</tr>
<tr>
<td>Total</td>
<td>135.42</td>
<td>134.09</td>
<td>153.78</td>
<td>146.99</td>
<td>158.40</td>
<td>151.56</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: US Department of Agriculture USA, calculations of the National Bank.
The main importers are countries of MENA (Middle East and North Africa); their share in world imports is 33%. It should be noted that Asia has reduced purchases of grains in the last 7 years by 11.7%, which mainly the role of China can be traced, which for 37 years has reduced wheat imports by 75% and for 7 years by 30%. The share of Europe in global wheat imports is
25%, Africa accounts for 23.5%. Purchase of wheat by countries of North and South America has been increased by 5.3 and 3.3 times, respectively.

The main importer of wheat is now Brazil, its share in world wheat imports is 5.5%. Brazil prefers growing feed grains and more export-oriented crops, so wheat grain imports have increased by 3.5 times over this years (Table 3). The second place is taken by Italy. Since 1970, its procurement of wheat had been constantly growing and in 2007 it imported 5.6 times more grain than in 1970. But it is typical for Italy, since its agriculture is focused more on southern crops and less on grain. Over these years Japan has purchased on average 5.3 million tons of wheat and, despite the increase in productivity, this production there does not manage to meet the needs for food. For 37 years Indonesia has increased the purchase of wheat by 16.3 times; the reasons are the growing population, low yields and natural conditions.

Most wheat is exported in the form of seeds and only 10.7 million tons are exported as wheat flour. Grains are easier to store and transport and flour is usually subject to customs duty. Countries with intensive livestock farming are interested in bran for fattening animals. Some countries (Germany), even specially import wheat in the amount exceeding their needs; bags of flour are taken out and bran remains.

The largest wheat flour exporters are Asia (4.8 million tons) and Europe (3.6 million tons). America exports 1.6 million tons of wheat flour. Although global wheat flour import is 10.5 million tons. Asian countries have imported 4.8 million tons (33% of the world’s figure); Europe has imported 2.2 million tons (25% of the world’s figure); Africa has imported 1.8 million tons; the figure of the Americas is 1.6 million tons.

In 2006/2007 MY season, the wheat market started experiencing the shortage of wheat in India and reduction in wheat production estimates in the United States, Australia, Ukraine, Russia and EU. In January 2007, according to USDA, the total reduction in world wheat production as compared to the 2005/2006 season constituted almost 30 million tons, and reduction in carry – over stocks was 25.2 million tons. Such situation led to gradual increasing prices. The first serious impetus for the significant increase in world market prices was major procurement of wheat (up to 5 million tons) by India. Australia, according to the tender results, became a major supplier of wheat to India, but a severe drought in the country forced the Australian monopoly AWB to terminate a number of export contracts and their obligations under the Indian tender were partially covered by the supply of wheat from other regions in the world, including the Black sea region.
The second impulse was reduction in the production of the main export type of wheat in the countries of EU, especially in the Eastern Europe Countries. The third factor in increased wheat prices was the decision of the Ukrainian government to impose restrictions on export of grain by quotas.

The intense global wheat balance and limited supply in the current season because of repeated droughts in Australia, rated higher and dramatically increased exports of Russian wheat. As a result, Russia imposed export duties (10% on wheat and 30% on barley). Adverse weather conditions in Argentina (frosts) led to a decrease in yield of wheat in the country by about 2 million tons in a few weeks. As a result, the government increased export duty on wheat by 8% up to 28%, and suspended the issuing of export licenses. High world prices make the largest wheat importers to shorten procurement volumes (Galushko et al, 2011).

8. UKRAINE: ITS ROLE AND PLACE IN THE WORLD GRAIN MARKET

Grain trade in Ukraine can be traced back to ancient times. Nearly half of all grain grown went abroad through ports of the Azov and Black Seas and the share of Ukraine’s exports of wheat in the Russian Empire was 90% (Mel’nik, 2010). The legend of Ukraine as a European breadbasket is also associated with grain production volumes in the Ukrainian villages in the second half of the nineteenth century–the first decade of the twentieth century, when nearly a half of export of grain was provided by landowners and farms. Ukraine being a part of the Russian Empire gained the status of “breadbasket” when its share in wheat exports reached 90%. On Ukrainian lands, 43% of the global barley harvest, 20% of wheat and 10% of corn was harvested. Export of Ukrainian wheat in the late 19th century and till the First World War played an important role in the economy of the empire. In 1910-1911 the Ukrainian province produced 19.6 million tons of grain per year, of which 4.9 million tons (nearly a quarter of yield) were exported, primarily to Germany (Zolotarev, 1925).

The revolutionary agrarian reforms of Bolsheviks actually destroyed the social and economic structure of grain production, that’s why “the breadbasket of Europe,” especially in arid 1921, became dependent on grain imports, with no grain for nutrition, seeding and livestock. The dynamics of foreign trade of Ukraine for 1921-1924 was characterized by growth, but in late 1924 a trend towards recession was already traced because exports of grain decreased.
Grain market experts considered Ukraine the traditional grain exporter. Former glory of “the European breadbasket” allowed all-Union procurement offices to see Ukraine as a major exporter of grain, given its geographical position, network of ports and railways. “What does Soviet Ukraine trade in”—wrote A.A. Zolotarev in 1925—of course, bread.” Of the total exported goods for the amount of 93.6 million rubles, bread was sold in the amount of 85.1 million rubles, i.e., 91%; in addition, almost 60% of the grain was rye, wheat was about 22%, barley constituted 12% and corn accounted for 5%. Our export in 1923-1924 was “rye” (Zolotarev, 1925).

Al’terman was an authoritative grain farming scholar of this period. According to his calculations, Ukraine during the second half of 1920ies, except for 1928-1929, exported 227-250 million tons of grain to the European market, which were 165-180 million pounds less than in 1910-1913, and the reason for this recession, to his opinion, was the consequences of revolutionary changes in the countryside and the destruction of landlordism, limiting of wealthy peasants (Al’terman, 1928).

In 1928 A. Al’terman published data in his book revealing the structure of grain exports, including the proportion of grain exported to the Soviet republics. If the pre-revolution grain turnover was mainly wheat–barley (75% of the commodity weight), the NEP turnover was wheat–rye (86%). The statistics of the Ukrainian grain market, which was developed by A. Al’terman, showed a decrease of exports, but with due account for the volumes exported to the Soviet republics, which showed the emergence of the “breadbasket” of union importance. Thus, in 1923-1924 Ukraine exported 248.5 million pounds of grain, of which in domestic market 80 million pounds were exported to Belarus and 83.4 million pounds were exported to Russia, and the export volume was 85.1 million pounds. But the next year, exports decreased to 42.5 million, and increased in 1926-1927 to 56.2 million tons; 89.6 and 82.6 million tons of grain were taken to the neighboring Soviet republics, respectively (Al’terman, 1928).

In 1925 Ukraine as the Soviet breadbasket was the subject of union and export grain procurement. Corn exports took half the value of agricultural exports, i.e., relatively high yield equalized imbalance of exports. The main consumers of Ukrainian grain were European countries. Thus, in 1925-1926 wheat exported mainly to England, Italy, Belgium and France; rye was exported to Sweden, Germany, Holland, England; barley was purchased by England, Germany, Belgium and corn was supplied to England, Sweden and France (Al’terman, 1928).
It was believed that the export of grain to the state cooperative farms was profitable, given the scarce procurement prices for farmers and export, but the dynamics of foreign exchange earnings showed its instability. Ukraine’s export opportunities were limited. It failed during the NEP years to achieve even half of the pre-war volumes of grain export, thus ceased to be “the breadbasket of Europe.”

Scarcity of grain crops in Ukraine in 1928 due to freezing of crops had a negative impact on grain procurement and export.

Article of V. M. Soloveichik (1928) noted that crops were 31-38% of gross agricultural production, and marketability did not reach even a third of the wholesale fee (Soloveichik, 1928). He emphasized the instability of grain export resources, which tended to decrease.

So, finding out Ukrainian grain export volumes during the New Economic Policy period and comparing it with the pre-war period, it is necessary to state an undeniable fact of a catastrophic decline. Only in 1923 and 1926, Ukraine reached a quarter of pre-war exports, and in subsequent years the figure was relatively low. The main reason for the decline of exports, according to the analysis of the 1920s literature by the authors which were known analysts, were agrarian reforms of Bolsheviks, i.e., the destruction of landlordism and economic constraints on farms, the share of which accounted for the bulk of grain export. Bet on state and collective farms made in 1919 was false because they gave only 4% of the grain commodity weight in Ukraine.

The grain volume of USSR and the Ukrainian Soviet Socialist Republic in 1920s for export could not compete with the offer of the world’s main producers – the United States, Canada, Argentina and Australia. Traditionally, as before 1913, Ukrainian consumers of bread were European countries – Britain, Germany, Italy, France, Sweden, Holland, but it was small batches of grain. Ukraine, starting from the First World War and especially during the revolution and debilitating civil war, lost the glory of the “European breadbasket.”

After the Second World War, the idea of Ukraine as the breadbasket of Europe was lost. Interest in the Ukrainian agricultural production revived after the formation of the European Union, primarily on the part of Germany and Austria. The German business press occasionally publishes articles under the title: “Breadbasket of Eastern Europe offers huge opportunities.” “Return of the European Granary” (Soloveichik, 1928).

Since the early 1990s, Ukraine is a significant economic and independent player on the world grain market, mainly as an exporter. In other words, the grain sector in Ukraine is” ... a strategic and export-oriented, which in its

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potential volumes is capable of impacting the global food security. Fluctuations in world grain production proportions causes tension not only in the agricultural sector, but also in the social sector, which requires constant monitoring of dynamics in changes of its volume and analysis of grain market development trends in certain producing countries” (Soloveichik, 1928).

The promising grain industry plays a significant role in the development of the agricultural sector of Ukraine. Corn is a strategic product and a barometer of the state of agriculture, an important export product that should provide significant amounts of currency. In all parts of the country, grain demand remains steady. This suggests liquidity of agricultural products. Corn has good portability and storage level so it creates an opportunity for Ukraine to form government strategic reserves. Besides, grain is the most exported product, through which the state can achieve stability of the currency.

In recent years Ukraine has become one of the leading exporters of grain on the world food market. Export crops perform a vital function for preserving a positive trade balance.

The grain market is a system-integrated market of AIC of Ukraine, having a significant production and export capacity. According to the State Statistics Committee, the planted area in 2015 for crops make up 58% of the national acreage, the grain share in the total value of crop production is 40%.

Changes in foreign policies of Ukraine toward closer economic integration with the countries of EU, accession to the WTO, the existing economic and agriculture potential allow domestic enterprises not only satisfy the domestic market, but also actively participate in international trade. Export of grain takes an important place in the export of agricultural products.

For 2015, the overall export of Ukraine to the EU countries totaled 13,015.2 million US dollars and decreased as compared to 2014 by 23.5% (by 3987.7 million US dollars), imports were 15,330.2 million US dollars and declined by 27.2% (by 5,739 million US dollars). The negative balance was 2,315 US dollars. The largest volumes of exports to the EU countries accounted for agricultural and food products–31.2% of total exports, ferrous metals equaled 20.2%, electrical and mechanical machinery amounted to 13.8% mineral products were 11.4%.

Cooperation of Ukraine with the EU in 2015. Among the goods of AIC and food industries, the largest share of exports accounted for crops, i.e., 40.2% of the total volume of AIC goods (including corn–31.5%, wheat–7.3%), fats and oils of animal or vegetable origin equaled 16.8% (sunflower oil–14.1%), seeds and oleaginous fruits amounted to 15.9%. The largest export of grain grown in Ukraine falls on the European Union (Table 8, Figure10). In 2012 the EU market purchased 7.7 million tons of grain in the amount of 1.9 billion US dollars.

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Table 8. Ukraine’s foreign trade in grains with the world’s countries, including the European Union in 2007-2015

<table>
<thead>
<tr>
<th>Years</th>
<th>Export, million US dollars</th>
<th>Imports, million US dollars</th>
<th>Exports to EU countries, million US dollars</th>
<th>% exports to EU in total exports</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>763.7</td>
<td>86.6</td>
<td>624.08</td>
<td>81.72</td>
</tr>
<tr>
<td>2008</td>
<td>3703.8</td>
<td>146.5</td>
<td>962.30</td>
<td>25.98</td>
</tr>
<tr>
<td>2009</td>
<td>3556.2</td>
<td>98.5</td>
<td>454.27</td>
<td>12.77</td>
</tr>
<tr>
<td>2010</td>
<td>2467.1</td>
<td>145.6</td>
<td>158.12</td>
<td>6.41</td>
</tr>
<tr>
<td>2011</td>
<td>3617.1</td>
<td>219.9</td>
<td>1031.62</td>
<td>28.52</td>
</tr>
<tr>
<td>2012</td>
<td>6999.9</td>
<td>249.1</td>
<td>1982.99</td>
<td>28.32</td>
</tr>
<tr>
<td>2013</td>
<td>6351.7</td>
<td>306.5</td>
<td>1722.59</td>
<td>27.12</td>
</tr>
<tr>
<td>2014</td>
<td>6544.1</td>
<td>366.6</td>
<td>1805.40</td>
<td>27.59</td>
</tr>
<tr>
<td>2015</td>
<td>6057.5</td>
<td>154.7</td>
<td>1625.80</td>
<td>26.84</td>
</tr>
</tbody>
</table>

Year 2012 turned out to be successful for Ukraine in terms of consolidation in foreign markets. This is evidenced by the fact that domestic grain has been actively purchased by European countries that 5 years ago doubted its quality. The European Union remains one of the major trading partners of Ukraine. In recent years, the share of grain export in the EU ranges between 25-28% of the total exports. Key figures of foreign trade of Ukraine in grains are listed in the Table 9.

Table 9. Key figures of foreign trade of Ukraine in grains

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Export of grains</td>
<td></td>
<td>122.8</td>
<td>1500.0</td>
<td>2467.1</td>
<td>3617.1</td>
<td>6999.9</td>
<td>6351.7</td>
<td>6544.1</td>
<td>6057.5</td>
</tr>
<tr>
<td>Imports of grains</td>
<td></td>
<td>118.4</td>
<td>150.5</td>
<td>145.6</td>
<td>219.9</td>
<td>249.1</td>
<td>306.5</td>
<td>366.6</td>
<td>154.7</td>
</tr>
<tr>
<td>Balance of foreign trade in grains</td>
<td></td>
<td>4.4</td>
<td>1349.5</td>
<td>2321.5</td>
<td>3397.2</td>
<td>6730.8</td>
<td>6045.2</td>
<td>6177.5</td>
<td>5902.8</td>
</tr>
<tr>
<td>Foreign trade turnover in grains</td>
<td></td>
<td>241.2</td>
<td>1650.5</td>
<td>2612.7</td>
<td>3837.0</td>
<td>7249.0</td>
<td>6658.2</td>
<td>6910.7</td>
<td>6212.2</td>
</tr>
<tr>
<td>Export to import coverage ratio</td>
<td></td>
<td>1.1</td>
<td>9.9</td>
<td>16.9</td>
<td>16.5</td>
<td>28.1</td>
<td>20.7</td>
<td>17.9</td>
<td>39.2</td>
</tr>
</tbody>
</table>

Source: based on the data of the State Statistics Service of Ukraine.
When determining Ukraine’s place in the global trade in grains. It is worth noting that a considerable part of grain is exported. The share of export of grains in Ukraine’s foreign trade is significantly higher than that of imports.

For Ukraine 2014 was remarkable in terms of grain harvest (63.9 million tons of grains), according to the Ministry of Agriculture. In 2015 the grain harvest was 6% less than in the previous year, but despite this fact, the unprecedented wheat export was recorded in that year and 37.4 million tons of grains in the amount of 6,057.5 million US dollars were shipped abroad.

According to “AIC-Inform” that published the “grain” exporters rating, the largest exporter, as in the previous season, was Ukrainian agricultural company “Nibulon.” In MY 2014-2015, the company supplied 4.2 million tons of grains and oilseeds to foreign markets. In MY 2015-2016, Nibulon opened up several new export destinations: China, Thailand and Mexico. The latter deserves special attention given the country’s geographical remoteness and proximity to the leading agricultural producers – the United States and Argentina. These countries traditionally take a strong market position in the western hemisphere.

![Figure 10. Foreign trade of Ukraine in grains with the EU countries.](image-url)
The dynamics of trade balance, which can be traced in a greater time period, confirms the lack of stable trends in Ukraine’s foreign trade (Table 10).

**Table 10. State of Ukraine’s Foreign Trade (million US dollars)**

<table>
<thead>
<tr>
<th>Indexes</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>The foreign trade turnover</td>
<td>33376</td>
</tr>
<tr>
<td>Exports of goods and services</td>
<td>18059</td>
</tr>
<tr>
<td>Agricultural export products</td>
<td>734.2</td>
</tr>
<tr>
<td>Export of grain</td>
<td>122.8</td>
</tr>
<tr>
<td>Imports of goods and services</td>
<td>15317</td>
</tr>
<tr>
<td>Imports of agricultural products</td>
<td>407.3</td>
</tr>
<tr>
<td>Imports of grain</td>
<td>118.4</td>
</tr>
<tr>
<td>Balance of trade</td>
<td>2742.5</td>
</tr>
</tbody>
</table>

Source: based on the data of the State Statistics Service of Ukraine.

During 2000-2012, the turnover increased by 5.2 times. Further, under the influence of the financial and economic situation in the country, there go three years of decline in trade turnover with subsequent rapid almost double decline, which is still taking place now. The foreign trade balance, after having been kept at the positive level since 2010, changed to negative. In 2014, under the conditions of a significant drop in turnover, the surplus was resumed, but this was due to the more rapid reduction in imports than in exports (exports in 2015 decreased by 27%, imports declined by 29.2%).

In turn, the state of foreign trade of agricultural products in Ukraine can be analyzed based on data from Table 11.
Table 11. The main value of external trade of agricultural products
Ukraine, mil. US dollars

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreign trade turnover in agricultural products</td>
<td></td>
<td>1141.5</td>
<td>6991.1</td>
<td>15699.7</td>
<td>19150.8</td>
<td>25756</td>
<td>25624</td>
<td>22771</td>
<td>18364</td>
</tr>
<tr>
<td>Exports of agricultural products</td>
<td></td>
<td>734.2</td>
<td>4307</td>
<td>9936.1</td>
<td>12804.1</td>
<td>17880.6</td>
<td>17024</td>
<td>16671</td>
<td>14564</td>
</tr>
<tr>
<td>Agricultural products export share in general national exports, %</td>
<td></td>
<td>4.07</td>
<td>9.70</td>
<td>15.73</td>
<td>15.58</td>
<td>21.70</td>
<td>22.27</td>
<td>26.01</td>
<td>31.12</td>
</tr>
<tr>
<td>Imports of agricultural products</td>
<td></td>
<td>407.3</td>
<td>2684.1</td>
<td>5763.6</td>
<td>6346.7</td>
<td>7875.4</td>
<td>8600.0</td>
<td>6100.0</td>
<td>3800.0</td>
</tr>
<tr>
<td>Agricultural products import share in general national imports, %</td>
<td></td>
<td>5.93</td>
<td>6.14</td>
<td>8.71</td>
<td>7.14</td>
<td>8.62</td>
<td>10.17</td>
<td>10.04</td>
<td>8.84</td>
</tr>
<tr>
<td>Agricultural products foreign trade balance</td>
<td></td>
<td>326.9</td>
<td>1622.9</td>
<td>4172.5</td>
<td>6457.4</td>
<td>10005.2</td>
<td>8424</td>
<td>10571</td>
<td>10764</td>
</tr>
<tr>
<td>The coverage ratio of export import</td>
<td></td>
<td>1.80</td>
<td>1.60</td>
<td>1.72</td>
<td>2.02</td>
<td>2.27</td>
<td>1.98</td>
<td>2.73</td>
<td>3.83</td>
</tr>
</tbody>
</table>

Source: based on the data of the State Statistics Service of Ukraine.

It should be noted Ukraine has a potential as a major exporter of agricultural products. Over the analyzed period, there has been a tendency to increase in the share of exports of agricultural products in the general state export from 4.1% in 2000 to 31.1% in 2015, while in recent years a decline in the share of agricultural imports has been observed, which indicates an increase of security in the country’s own agricultural products. The import-export ratio is of primary importance in

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terms of foreign trade security. The data given shows that export revenues fully cover the cost of importing. It plays a positive role in the country development.

Liberalization and patronage not only personify objective and subjective contradictions that constantly arise in the global market, but have to overcome them through appropriate effective economic mechanisms. Content wise, the mechanism of liberalization and protectionism, according to V.I. Hubenko, is a dynamic system of international relation, connected with purposeful movement of capital between countries and a relevant regulatory function of public administration aimed at protecting national interests (Prisyazhnyuk et al., 2011).

Studies show that an increase in agricultural production in Ukraine has led to an increase in agricultural exports. According to the State Statistics Service, the share of exports of agricultural products in the structure of Ukraine’s total exports in 2015 was 31.12%. At the same time, the volume of AIC products export grew by 3.4 times up to 14.6 billion US dollars (Table 12). An export of these products by 58% covers imports. In Ukraine, the foreign trade balance by four groups of agro-food products is generally positive, and food export is almost 2.4 times more than its import.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop production</td>
<td>1695.8</td>
<td>5034.9</td>
<td>3976.3</td>
<td>5532.1</td>
<td>9213.9</td>
<td>1083.1</td>
<td>1014.5</td>
<td>823.4</td>
<td>0.16</td>
</tr>
<tr>
<td>Animal products</td>
<td>732.2</td>
<td>596.0</td>
<td>771.4</td>
<td>936.6</td>
<td>961.3</td>
<td>8849.1</td>
<td>8736.1</td>
<td>7971.5</td>
<td>13.38</td>
</tr>
<tr>
<td>Production of oil-fat industry</td>
<td>587.2</td>
<td>1796.0</td>
<td>2617.3</td>
<td>3396.4</td>
<td>4211.5</td>
<td>3497.4</td>
<td>3822.0</td>
<td>3299.8</td>
<td>1.84</td>
</tr>
<tr>
<td>Food products</td>
<td>1291.7</td>
<td>2088.0</td>
<td>2571.1</td>
<td>2939.0</td>
<td>3493.9</td>
<td>3500.5</td>
<td>3096.3</td>
<td>2468.4</td>
<td>1.18</td>
</tr>
<tr>
<td>Exports of AIC– all</td>
<td>4307.0</td>
<td>9514.9</td>
<td>9936.1</td>
<td>12804.1</td>
<td>17880.6</td>
<td>16671</td>
<td>14564</td>
<td>3.38</td>
<td></td>
</tr>
</tbody>
</table>

Source: based on the data of the State Statistics Service of Ukraine.

In the global market, Ukraine makes export and import transactions in agri-food products with 117 countries at various segments of the global market: Asia, Europe, Africa and other countries. More than half the volume of exports of domestic AIC products is provided for by plant origin (51.5%), mainly due to the sale of grains: wheat, corn, barley. This has led to a
significant expansion of trade relations in the world grain market. Thus, in 2005 the export geography included 75 countries, in 2012 this figure reached 101, i.e., 26 countries more. The main importers of Ukrainian wheat in 2005-2012 were Spain, Egypt, Israel and Tunisia, which over the years have imported 7.6, 6.0, 4.2 and 3.0 million tons, respectively (Sabluk, 2009). The main partners of Ukraine in corn imports are Belarus, Spain, Iran, Tunisia and Egypt respectively having purchased 1.1; 5.5; 3.9; 1.8 and 8.2 mil. tons respectively (Sabluk, 2008). The main importers of barley were the Middle East: Saudi Arabia, Iran and Jordan, which had exported over 18.3 million tons from Ukraine for 2005-2012.

Exports of agricultural products from Ukraine in 2015 amounted to 14.6 billion USD. It exceeded imports by 11.1 billion US dollars – an unprecedented record for the country since its independence. Exports of agricultural products in Ukraine for the year exceeded imports by unprecedented 11 billion US dollars.

The basis of the commodity structure of Ukrainian agricultural exports was grains – 16% of total exports, fats and oils – 9%, and oilseeds – 4%. Despite the unfavorable price situation in the world markets for 12 months in 2015 we’ve got a positive balance of foreign trade in AIC – 11.1 billion US dollars. This is a record figure in the history of Ukraine’s independence. The positive balance of foreign trade in agricultural products in 2015 increased by 0.4 billion US dollars, compared to 2014 and by 1.9 billion US dollars compared to 2013. The total volume of export of Ukrainian agricultural products for the last year was 14.6 billion US dollars. At the same time the share of exports of agricultural commodities in the commodity structure of Ukraine’s exports in 2015 was also an unprecedented figure – 38.2%. The basis of the commodity structure of Ukrainian agricultural exports were grains – 16% of total exports, fats and oils – 9% and oilseeds – 4%. The surplus of foreign trade in Ukraine increased by 2.6 times. In 2014 Ukraine exported agricultural products in the amount of 16.7 billion US dollars, i.e., 1.8% less than in the previous year. An agricultural import to Ukraine in 2014 was reduced by 25.8% up to 6.1 billion US dollars. The most exported Ukrainian agricultural products in 2014 were sunflower oil (21.3% of total AIC exports), corn (20.1%), wheat (13.7%), mill cake, except for soybean and peanut –5.6% and rape (5.2%). Thus, the supply of grain abroad accounted for 39% of total exports of agricultural products from Ukraine and fats and oils corresponded to 23%.
9. PORT TERMINALS FOR GRAIN EXPORT FROM UKRAINE

Export of grain is for more than 90% provided by transportation on ships of Ukraine. The main flow (over 60%) through grain terminals in the ports is from June till December, and the peak is in November-December, when the capacities are loaded at 90%. According to the Transport Strategy Center, the capacity for transshipment of grain in Ukrainian ports is about 44.1 million tons per year with the ability to simultaneously store nearly 2.4 million tons (Table 13). Usually the busiest three ports of Odesa (Odesa SP, Pivdennyi, Illichivsk, Mykolaivsky SP and terminals of Nibulon and Avlita.

Table 13. Characteristics of Sea Ports for Transshipment of Grain in 2013

<table>
<thead>
<tr>
<th>Port/Terminal</th>
<th>Volume of simultaneous storage, thous. tons</th>
<th>Annual capacity, mil. t</th>
<th>In%, total</th>
<th>Annual capacity, mil. t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odesa SP</td>
<td>340</td>
<td>6000</td>
<td>14.2</td>
<td>13.6</td>
</tr>
<tr>
<td>TIS (Pivdennyi)</td>
<td>290</td>
<td>4800</td>
<td>12.1</td>
<td>10.9</td>
</tr>
<tr>
<td>Illichivsk SP</td>
<td>200</td>
<td>4000</td>
<td>8.4</td>
<td>9.1</td>
</tr>
<tr>
<td>Bunge (Mykolaiv)</td>
<td>140</td>
<td>4000</td>
<td>5.9</td>
<td>9.1</td>
</tr>
<tr>
<td>Avlita (Sevastopol)</td>
<td>170</td>
<td>3500</td>
<td>7.1</td>
<td>7.9</td>
</tr>
<tr>
<td>Illichivsk SRH</td>
<td>120</td>
<td>3500</td>
<td>5.0</td>
<td>7.9</td>
</tr>
<tr>
<td>Nibulon (Mykolaiv)</td>
<td>130</td>
<td>3000</td>
<td>5.4</td>
<td>6.8</td>
</tr>
<tr>
<td>Brooklyn-Kyiv</td>
<td>240</td>
<td>3000</td>
<td>10.1</td>
<td>6.8</td>
</tr>
<tr>
<td>Borivazh- (Pivdennyi)</td>
<td>130</td>
<td>2000</td>
<td>5.4</td>
<td>4.5</td>
</tr>
<tr>
<td>Mykolaivsky SP</td>
<td>170</td>
<td>2000</td>
<td>7.1</td>
<td>4.5</td>
</tr>
<tr>
<td>Nika-Tera (Mykolaiv)</td>
<td>140</td>
<td>2000</td>
<td>5.9</td>
<td>4.5</td>
</tr>
<tr>
<td>Khersonsky SP</td>
<td>120</td>
<td>1200</td>
<td>5.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Other</td>
<td>198</td>
<td>5140</td>
<td>8.3</td>
<td>11.6</td>
</tr>
<tr>
<td>Together</td>
<td>2388</td>
<td>44140</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: based on the data of the State Statistics Service of Ukraine.

In 2013/2014 MY through seaports Ukraine exported a record amount of grain, as well as throughput of ports and terminals was increased (Table 14, Figure 11). In addition, Ukraine in 2013/2014 MY exported a record amount of grain in containers. The modernization of some grain trans-shipping enterprises and commissioning of new facilities made it possible to produce about half of the grain export from Ukraine with large tonnage fleet.

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Table 14. Dynamics of Grain Transshipment by Ukrainian Seaports, thous. Tons

<table>
<thead>
<tr>
<th>Ports</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2015 in% to 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIS (Pivdennyi)</td>
<td>6165.3</td>
<td>9139.8</td>
<td>9760.0</td>
<td>158.3</td>
</tr>
<tr>
<td>Mykolaiv</td>
<td>6938.7</td>
<td>6932.9</td>
<td>8760.0</td>
<td>126.2</td>
</tr>
<tr>
<td>Odesa</td>
<td>5338.6</td>
<td>6675.9</td>
<td>8610.0</td>
<td>161.3</td>
</tr>
<tr>
<td>Il’ichevsk</td>
<td>3835.5</td>
<td>4593.0</td>
<td>5090.0</td>
<td>132.7</td>
</tr>
<tr>
<td>SMT “Oktyabrsk”</td>
<td>1643.1</td>
<td>2241.8</td>
<td>2450.0</td>
<td>149.1</td>
</tr>
<tr>
<td>Berdyansk</td>
<td>681.6</td>
<td>1286.9</td>
<td>1000.0</td>
<td>146.7</td>
</tr>
<tr>
<td>Kherson</td>
<td>1354.7</td>
<td>1220.6</td>
<td>943.6</td>
<td>69.7</td>
</tr>
<tr>
<td>Mariupol</td>
<td>725.9</td>
<td>748.1</td>
<td>407.5</td>
<td>56.1</td>
</tr>
<tr>
<td>Reni</td>
<td>449.1</td>
<td>624.8</td>
<td>245.0</td>
<td>54.6</td>
</tr>
<tr>
<td>Ismail</td>
<td>14.4</td>
<td>65.7</td>
<td>159.7</td>
<td>1109.0</td>
</tr>
</tbody>
</table>

Source: according to UkrAgroConsult.

According to port sources, in 2013/2014 MY export shipment of grain through the ports of Ukraine reached the record figure of 31.5 million tons. The previous record export shipments through the ports were in 2008/2009 MY at 23.5 million tons.

In the first half of 2013/2014 MY, seaports of Ukraine reached a new record high monthly throughput capacity for grain handling—5 million tons were shipped in December 2013 due to favorable weather conditions and corn high-yield.

Grains in 2013/2014 MY were characterized by record volumes of grain shipments in containers. According to UkrAgroConsult, in 2013/2014 MY containerized grain exports from Ukraine totaled a record 190 thousand tons’ vs 66 thousand tons in 2012/013 MY and exceeded the previous record of 2008/2009 MY.

In 2013/2014 MY, the proportion of large fleet in grain exports from Ukraine increased to a record 49% compared to less than 10% in 2007/2008 MY. The share of small tonnage fleet in export shipments is declining, despite the development of river transport. In addition, in 2012/2013 MY Ukraine shipped the biggest batch of grain in the volume of 93 thousand tons.

In the Ukrainian ports for 2015, the volume of transshipment was 37.46 million tons of grain cargoes (including 36.84 million tons of grain), i.e., 10.5% (12.4%) more than in 2014. Transshipment by seaports of Ukraine for 2015: Pivdennyi – 9.76 million tons of grain cargoes, which is 6.8% more than in 2014; Mykolaiv seaport – 8.76 million tons (+26.4%); Odesa–8.61 million tons.
tons (+29%), Ilichivsk – 5.09 million tons (+10.9%); Berdiansk – 1.00 million tons (-22.2%), Kherson SP – 943.6 thousand tons (-22.7%); Mariupol port – 407.45 thousand tons (-45.5%), Ismail – 159.65 thousand tons (+143%).

Today, oldest port elevators – Odesa and Mykolaiv owned by the State Food and Grain Corporation of Ukraine, are being modernized. As a result, the Mykolaiv grain elevator transshipment capacity will increase by 35%. A series of modernization measures at the Odesa port elevator is also planned with the purpose to increase transshipment terminal capacities up to 3 million tons per year.

According to the Administration of Seaports of Ukraine, under the plan of modernization of ports, the Illichivsk port plans to increase its capacity for handling grain and leguminous cargoes by nearly 12 million tons, Pivdennyi – by 21 million tons, Odesa – by 5 million tons. The construction of the “Brooklyn” grain terminal at Androvsky Mol with the capacity of 4 million tons should be noted. It should be recalled that the first phase of the grain terminal was opened in 2013 – 11 tanks designed to store 72.4 thousand tons of grain.

Figure 11. The volume of grain transshipment by Ukrainian sea ports in 2015.
The capacity for storage of grain was increased at the “Nika-Tera” terminal, from 40 up to 210 thousand tons, which allowed the company in 2013/2014 MY to double the volumes of grain.

In the spring of 2014, a new grain terminal in the port of Ochakiv was commissioned with the capacity of 250 thousand tons. According to available data, in 2013/2014 MY, this terminal shipped 11.8 thousand tons of grain for export.

According to calculations of UkrAgroConsult, for the period of July 2015–March 2016 export shipments of grain cargoes through maritime ports of Ukraine have totaled 30.4 million tons, which is 12% more than in the same period of the last season (27.1 million etc.). In 2014/2015 MY exports of grain through the ports reached an unprecedented figure of 34.6 million tons.

Taking into consideration the record pace of exports and forecast of record grain exports from Ukraine, UkrAgroConsult expects that in this 2015/2016 MY shipment of grain through the ports can update the record of the previous season.

**CONCLUSION**

Among former members of Soviet Union – Kazakhstan, Russia and Ukraine have the highest potential for increase of food supplies and strengthening of food security in the world, which recently is becoming more important in establishment of the world agricultural market. Crops export from Black Sea ports was large-scale even at the end of 19th century. The situation has started repeating in recent times: in last years Ukraine has become one of the leading grain exporters on the world food market.

Global and regional consequences in change of climate results into rise of uncertainties in yield for main consumer agricultural crops. With a favorable combination of meteorological factors discontinuities in soil fertility, caused by both natural regularities and influence of agricultural production of various duration and intensity, are seriously leveled off. It was shown that as far as lands were being used for agricultural purpose and soil-degradation processes were being developed both leveling of differences in lands quality and fertility reduction at different rate depending on differences of primary fertility level took place. With an unfavorable combination of agroclimatic conditions the pattern of productivity space distribution is especially informative for non-correlated years, when soil fertility is shown most clearly. Complex comparable estimation of lands quality should become one of the most
important improvement mechanisms in new economic conditions. It permits to assess added profit in agriculture arising in labor productivity with equivalent expenses on lands with highest fertility and to create an objective basis for establishment of the fair land tax.

Rational use of land resources and introduction of adaptive argotechnologies in terms of changing climate is a guarantee of high stable yields and provision of competitive positions of agricultural producers. Introduction of innovative agrotechnologies ensured yield rise in average by 4.5 times and stabilization of agricultural production of the process by 2.2 times for last 150 years.

Grain market of the country is important indicator of the quality of economic reforms, implementation of agri-food policy. Grain market is characterized by its dynamism and rapid growth of supply. Grain market can serve as a kind of model of development other agricultural markets, raw materials and food. It includes almost all the elements of a market economy. The development of the grain market affects not only a wide range of issues relating to the functioning of the grain farming directly, but the whole agri-food complex.

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**BIOGRAPHICAL SKETCHES**

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### Research and Professional Experience:

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### Research Interests: ecoogy, soil science, soil geography, geomorphology, geoarchaeology, pedoarchaeology, the study of ancient systems of land use new scientific methods (GIS, remote sensing).

### Professional Appointments: Author, co-author of over 450 publications, including 15 books, 50 papers in peer-reviewed journals, and 22 of the objects of intellectual property (databases, computer programs).

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Honorary worker of higher professional education of the Russian Federation 2002
Diploma of the Russian ministry of Education 2001
full member (academic) of the International Science Academy of ecology and safety of the vital functions 2000
The corresponding member of Petrovskaya Academy of sciences and arts 1999
Laureate of the South center of scientific and technical activity contest, the investigations and social initiatives on the best scientific work in the sphere of ecology 1990

Publications Last 3 Years:

Book Chapters

Journal Publications

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Goleusov P.V., Lisetskii F.N., Chepelev O.A. Prisniy A.V. The rate of soil formation in regenerative ecosystems with various combinations of

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<td>Date</td>
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Research Interests: environmental sciences & ecology, agriculture, water resources, land and water resources, climate, modeling, forecasting, GIS technology, neural network.

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Chapter 2

CULTIVATION, COMMON DISEASES AND POTENTIAL NUTRACEUTICAL VALUES OF WATERMELON

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ABSTRACT

This review sought to provide information on cultivation, common diseases, and properties of watermelon, as well as a potential pharmaceuticals agent. Apart from disseminating details on growing of red- and yellow-fleshed watermelon plants from seed germination to harvesting, in this review we also focused on the insect pests and diseases that affect the watermelon plant and insecticidal control of these pests, a most commonly practiced in Malaysia. The presence of nutritional composition, as well as the bioactive compounds of watermelon fruit were also covered. In the present socio-economic scenario, searching, and practicing the proper cultivation technique and appropriate handling of tropical fruit, such as watermelon, could support the local population who depend on farming for a livelihood. Knowledge on the growth requirements and the potential insecticidal control of insect pests and diseases will facilitate large scale production and commercialization of the watermelon for international market. In addition, watermelon plants are widely cultivated for its large, sweet, juicy, and refreshing edible flesh, but there is also a need to ensure that their potential uses is exploited for its potential health benefits. Overall, the information on cultivation, common diseases, and properties of watermelon could provide a wide range of social and economic benefits, especially for food and pharmaceutical industries.

1. INTRODUCTION

Watermelon (scientific name: *Citrullus lanatus*; family: Cucurbitaceae; genus: *Citrullus*) is a non-seasonal tropical fruit of Southeast Asia (Kumar, 1985; Koocheki et al., 2007). For centuries, watermelon is known to have a positive effect on health and for its therapeutic properties (El-Razek and Sadeek, 2011). Its biomass can be categorized into three main components, which are the flesh, rind, and seed. The flesh constitutes approximately 68% of the total weight, the rind approximately 30%, and the seeds approximately 2% (Kumar, 1985). Watermelon thrive more in the tropical regions and enjoy worldwide popularity for its aesthetic tastes and nutritional compositions (Snowdon, 2008). Watermelons will continue to be a vital part of fruits production. Increases in average yield per acre will continue as intensive management practices such as good cultural practices and insect pests and diseases control practices are followed.
In this review, we discussed on the cultivation techniques of watermelon starting from seed sowing, planting, to seedling protection. In addition, we have provided information on the insect pests and diseases management and post-harvesting handling. The nutrition composition, bioactive compounds as well as the potential use of watermelon fruits and their waste (seed and rind) for pharmaceutical application were also covered. It is envisaged that the details discussed in this review will help to local population who depend on farming for a livelihood as well as exploit the potentiality of watermelon fruit at international market for food or pharmaceutical applications.

2. WATERMELON FRUIT

Watermelon is a climbing annual plant with several herbaceous, firms, and stout stems up to three meters. The young parts are densely woolly with yellowish to brownish hairs while the older parts are hairless (Erhirhie and Ekene, 2013). The production and consumption of this fruit are greater than that of any other species in the cucurbitaceae family (Robinson and Decker-Walters, 1997). It is grown for its edible fruit, also known as a watermelon, which is a special kind of berry botanically called a pepo.

The shape of the fruit is most commonly round to elongated and has a smooth, hard pale green exocarp (red-fleshed variety) or dark green exocarp (yellow-fleshed variety). Sometimes, the pale green stripes that will turn yellowish green when ripe (Perkins-Veazie and Collins, 2004). Both varieties have a juicy and sweet interior flesh (usually red-fleshed but sometimes pink or yellow- or orange-fleshed) (Yau et al., 2010). Watermelon has a layer of white-fleshed internal rind that varies in thickness; red-fleshed watermelon rind has thicker internal rind than yellow-fleshed watermelon rind. Seeds are absent or present inside but sometimes outside the edible flesh. Seeded watermelon has black or dark brown oval seeds, whereas seedless watermelon variety may not contain seeds or only very thin and small, jelly-like white seeds (Rushing, 2008; Yau et al., 2010).
3. CULTIVATION OF WATERMELON

3.1. Soils

Soil and its nutrient status affect the crop growth and yield. For seed germination and early seedlings growth, it requires sandy and loose texture soil. Maintaining the soil fertility during the growth and development of watermelon are necessary to obtain high yield. Watermelons can be grown on a wide range of soil types with sandy soils being preferred. However, the highest yields generally be produced on well-drained clay loam soils. Coarse, sandy soils are generally low in fertility and subject to moisture stress and require special care (more frequent, timely irrigation) to grow a good crop. In case of heavy soil, the plant growth is very slow, small fruit size, and quality are usually inferior. This crop needs dry coastal area and sandy or bris soil for better sweetness. Cultivation in sandy soils windbreaks are advisable practice on to reduce “sand blast” damage and stunting of young seedlings caused by spring winds. Watermelon is fairly tolerant to soil pH as low as 5.5, but grows best where soil pH is between 5.8 and 6.2. If the soil pH is below 5.5, soil treatment with lime is required. Soil temperature is one the most important parameter that can affect the growth and development of watermelon crop. It has been reported that low temperatures reduce the vegetative and reproductive growth of watermelon (Alan et al., 2007).

3.2. Land Preparation and Fertilizer Application

Like all cucurbits, watermelons need rich, well-draining soil. A location that receives full sun (8 to 10 hours of unfiltered sunlight) with plenty of space for the vines, which can grow to 15 feet or more is optimum for growth and development. Land preparation affects the growth of any type of crops. Soil tillage is one of the most important factors that can affect the soil physiological properties, crop growth, and yield. Tillage contributes up to 20% among the crop production factors (Khurshid et al., 2006). It has been reported that tillage methods significantly affect the watermelon yield, fruit weight, fruit length, fruit diameter and total soluble content in the flesh (Rashidi and Keshavarzpour, 2007). Tillage methods create positive effect on soil physical properties. They also reported that mold board plough followed by two passes of disc harrow is more appropriate and profitable tillage in watermelon cultivation which increase the soil physical properties and yield of...
Cultivation, Common Diseases and Potential Nutraceutical Values …

watermelon. Two to four weeks prior to planting the soil need to cover with black plastic. The soil must be thoroughly warmed before planting seeds or seedlings. In long-season areas, watermelon seeds directly sown into the field but the seedlings are raised in seed bed in colder areas with short growing seasons. The soil must be kept moist at the early stages of seedlings development.

The applications of compost tea or fish emulsion stimulate the growth of seedlings. Crop rotation practice is essential to prevent disease buildup and avoid soil depletion. Long-term continuous monoculture of watermelon crops can develop serious problems, such as low seed germination rates, high seedling mortality, stunted plant growth, leaf yellowing, morbidity, blight, and leading to low fruit yield and quality (Yang et al., 2016). Crop rotation of land out of watermelon cultivation is the oldest management practice to relieve continuous cropping problems and improved the yield and quality. Yang et al., (2016) reported that both cattle manure application and garlic rotation can ameliorate the negative effects of continuous cropping and the combined application of cattle manure addition and green garlic rotation increased the yield, reduced disease incidence, and enhanced soil quality.

For proper growth and development, watermelon need heavy doses of nitrogen and therefore required a liberal application of 200 kg/acre. Before sowing, NPK (Nitrogen:Phosphate:Potash) compound fertilizer also needs to be applied, followed by application of nitrogenous fertilizers at 5-weeks intervals up to flowering stage (Rice et al., 1986; Schippers, 2000). Two inches of compost or manure over the garden area increased the growth and development of watermelon. Organic matter, such as compost, increases nutrients in the soil, improves structure and drainage, and helps to balance pH of the soil. To improve drainage condition of the soil, it is required to add builder’s sand. Ojo et al., (2014) reported that tropical soils are beset with the problems of nutrient loss due leaching, acidity, low nutrient contents, nutrients imbalance and soil erosion. For better growth and yield of watermelon, it is necessary to supplement the nutrient status of the soil to meet the crop’s need. The use of organic materials such as poultry manure, farm yard manure, animal waste and use of compost or with the use of inorganic fertilizers increased the nutrient status by boosting the soil nutrient content (Dauda et al., 2005).

Gordon et al., (1993) suggested that the continuous use of chemical fertilizer lead to high crop yield but may cause pollution of ground water after crop harvest and create adverse effects on plant growth and quality. It has been reported that continuous dependence on chemical fertilizers may be

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accompanied by a decline in soil organic matter content, increased soil acidity, degradation of soil physical properties, and increased rate of erosion due to instability of soil aggregates (Adeoluwa and Adeogun, 2010). Ojo et al., (2014) reported that organomineral fertilizer Grade A at 2.5 metric ton/hectare can be adopted for watermelon cultivation in tropical conditions. Sabo et al., (2013) recommended that the use of 150 kg NPK/hectare at a spacing of 1 × 1.5 m increased watermelon production in tropical conditions. They also reported that optimum rate of NPK fertilizer and plant spacing increased the number of flower, number of fruits, weight of fruits, yield per hectare, and improve the fruit quality of watermelon.

3.3. Sowing

In watermelon cultivation, there are two types of sowing patterns followed by the farmers; direct sowing and mulching method. In direct sowing method, the land is ploughed three or four times by the tractor. After preparing the soil, seed is drilled uniformly in the row at a 1 to 1½ inch depth (3/4 to 1 inch depth for small seeded varieties). Diammonium phosphate (DAP), borate and farm yard manure should be mixed with soil before drilling of seed. Two or three seeds are sowed into each pit or drill. One kilogram of seed is required for 2½ acres. Two times weeding is required for early establishment of plant. For the first fifteen days, pot watering is carried out and then flood irrigation is followed by the farmers. After one month raised beds are made with a distance of 6 cm between each bed and complex urea and DAP are required to apply to the plants.

In mulching method, land is ploughed three or four times by the tractor. Raised beds are made manually or with the help of machine. The breadth of raised beds is two centimeters and bed to bed distance is 10 cm. Black polythene mulching sheet are used to cover the raised beds and holes in the bed. Hence seedlings (2 to 3 weeks old) are planted into the pits. Different mulching practices such as whole mulch (WM), rows mulch (SM), and root domain mulch (RM) can play a significant role to watermelon crop growth and yield. Sun et al., (2004) reported that the WM, SM, and RM treatments significantly improved the yield and the water use efficiency and the WM straw mulch is the best cultural practices for watermelon production in arid areas due to its favorable effect on soil storage moisture, yield, and water use efficiency. The usage of polyethylene (PE) mulches and drip irrigation increased the watermelon yield and quality (Ban et al., 2009). Cultural
practices such as the implementation of plant density strategies, nutrient management, and arbuscular mycorrhiza (AM) inoculation have been reported to have a significant effect on watermelon growth and yield (Kaya et al., 2003; Goreta et al., 2005). Edelstein and Nerson, (2002) reported that for seed production, high plant density is recommended in watermelon because more fruit per area can be achieved. While, the fruit weight and other fruit quality could be negatively impacted by high plant densities (Motsenbocker and Arancibia, 2002; Goreta et al., 2005). Ban et al., (2009) stated that an in-row plant spacing of 1.0 m enhances the early plant growth and total yield while maintaining high fruit weight. They also reported that arbuscular mycorrhiza associations have significant effect on watermelon yield.

In pro tray nursery method seedlings are produced in the trays. Coco pit and pseudomonas are used as a germination media and then seeds are sown into the pro-trays. Seedlings are produced and transplanted in the holes of the mulching sheet within 2 to 3 weeks period. Seed should be planted approximately 1 inch deep in the pit of germination tray. The amount of seed required (usually 1 to 2 pounds/acre) depends upon seed size, germination and plant spacing. Correctly labeled, uniform, disease free, certified seed with 85 to 90% germination is preferred.

3.4. Hardening-Off

For hardening-off period, 3 to 4 days are sufficient for watermelons crops. Hardening-off can be initiated by reducing greenhouse temperature and by withholding water or limiting fertilizer. Hardened plants are able to withstand chilling stress, mild water stress, drying winds or high temperatures. Compared to unhardened plants, hardened plants can produce new roots rapidly. However, overly hardened plants grow slowly and in severe cases never fully recover (Boyhan et al., 2000).

3.5. Planting

There are several methods of planting watermelon. Precision seeding equipment, plug mix planting, and transplants reduce or eliminate the need to thin stands after planting.
3.5.1. Plug Mix Planting

Plug mix planting consists of blending watermelon seeds, fertilizer, and water with a growing medium of approximately one-third vermiculite and two-thirds peat. Prepared in cement mixers, the mix often is allowed to remain in bags for 24 to 48 hours prior to planting to allow seed to absorb water and begin the germination process. Precision plug mix planters dispense the mix in the field by injecting $\frac{1}{8}$ to $\frac{1}{2}$ cup of mixture (plug) per hill. The mix should have enough seed to dispense from three to five seeds per hill. Plug mix planting is especially advantageous when planting watermelon seeds in plastic mulch. These planters punch or burn holes in the plastic to insert the mix.

Watermelons traditionally have been spaced 6 to 8 feet between hills on bare ground without irrigation. With irrigation, use a spacing of 5 to 6 feet between hills. With plastic mulch and trickle irrigation, use an in-row spacing of 3 feet and between-row spacing of 6 to 8 feet. Icebox watermelons can be spaced even more closely, with in-row spacing of 2 feet and between-row spacing of 5 feet (Boyhan et al., 2000).

3.5.2. Transplant

A watermelon transplant should be set slightly deeper than grown in the greenhouse. This helps prevents damage at the root/stem interface that can occur due to blowing winds. Peat pots should not have any portion remaining above ground because the pot itself will act as a wick to draw moisture from the soil, often desiccating the roots or frequently causing moisture stress. Finally, transplants should be watered as soon as possible after transplanting to remove air pockets surrounding the roots and to ensure sufficient soil moisture for good root establishment. Many transplanting rigs are capable of delivering water to each transplant as it is set. Apply fertilizer solution to each transplant, especially if fertilizer requirements during transplant production were from the media exclusively. Use a water-soluble fertilizer such as 10-34-0. Mix 1 quart of this material in 50 gallons of water. Apply about $\frac{1}{2}$ pint per transplant (Boyhan et al., 2000).

3.6. Irrigation and Weeding

Irrigation at regular interval is very important for watermelon production. The water need to be irrigated around 1 to 2 inches. Irrigation in the late afternoon or night results in an increase the foliage disease to the crop. Proper irrigation during the flowering, fertilization and fruit set is essential.
Deficiently of water during these stages will affect the leaf area and yield of crops. The optimum irrigation is essential to make sure the fruit growth, development, and maturation of watermelon fruits. During fruit development, the moisture stress decreases the fruit size and rapid declination of vine. When the fruits are fully matured moderate irrigation is needed so as to prevent the fruits from explosion, white heart, and lower sugar content. Randomly, more than 90% of water contains in a ripe watermelon. So, the sufficient water supply is needed to increase quality of the fruits. Irrigation systems have several types which are sprinkler irrigation, scheduling irrigation, and drip irrigation. The types of irrigation systems will be applied, based on the several factors such as size and shape of field, equipment available, cost, availability of water amount, labor, and fuel requirements (Tyson and Harrison, 2013).

The sprinkler irrigation is one of the cooling irrigation system that usually used by farmers in watermelon crop to prevent airborne dust. This system gives advantages when it reduced the water loss. The water will be spray with circle rotation by using spray gun. However, the spraying water around the field will be increased the rate of pest population and plant disease.

For the scheduling irrigation system, highly experienced and expert skill are needed. The correct irrigation rates must be determined to avoid the over-moist condition of soil (Kerr, 2013). The excess irrigation will flush out of nutrients especially from root zone. Drip irrigation system is popular in watermelon cultivation because the efficiently of water uses (Bernstein and Francois, 1973) and decrease the energy supply in pumping (Orth, 1978). Some studies also reported that this system also produced the higher yield and increase the size of fruit than the other methods of water supply (Abdel-Razzak et al., 2016; Kachwaya et al., 2016; Hou et al., 2016). Drip irrigation system is followed in or without the mulching method. For the first 15 days, daily irrigation is done for an hour duration. For the next 15 days for 2 hours duration, and thereafter, until harvesting, for 3 hours duration. In addition, not only water but the fertilizer and chemical like pesticide also can be applied in water irrigation to the crop. Its advantages of minimized of water and fertilizer losses. Compare to sprinkler irrigation, the drip irrigation can avoid the plant disease that spreading by the water.

3.7. Pollination

Watermelon consists of two separate flowers: male and female flowers (Boyhan et al., 2013). For seed set and fruit development of watermelon, the
pollen of female flower will be transferred to male flower (Foord and MacKenzie, 2009). The use of bees for pollination has been very successful in watermelon cultivation. Placing one strong colony of bees every two acres in or alongside the field when blooms begin to appear increased the watermelon yield.

3.8. Fruit Pruning

Each melon vine produces a primary stem or leader with many secondary branches or laterals. Many melon cultivars produce extensive vine growth. Pruning the vines may be necessary if the melons are trellised. By performing pruning, a balance between vine growth and fruit set can be achieved. This can stimulate the flowering and fruit set of watermelon, increasing the average fruit weight and reducing the number of unmarketable (cull) fruit.

Fruit pruning in watermelons should begin as soon as defective melons are noted. Deformed and blossom-end rot fruit protect fruit set and growth of remaining watermelons in the vine. To avoid disease spread, do not prune melons when vines are wet because this will encourage parasites and diseases growth and spread. If a market demands larger melons, remove all but remained two or three well-shaped melons from each plant.

According to Buwalda and Freeman (1986), largest total fruit yields were recorded where the vines were not pruned. However, average fruit sizes decreased as the number of fruit per plant increased. Pruning the vines increased the proportion of marketable yield harvested in the first cut, indicating that fruit maturity was also advanced. None of the treatments significantly affected fruit sugar contents. Therefore, the vines of watermelon should be pruned in order to get high quality of fruits with large in size.

3.9. Field Maturity

Watermelons are considered optimum for eating when their flesh matures to produce a sweet flavor, crisp texture, and deep red color. Some newer cultivars, however, range in color from light red to yellow. Several indicators help to determine the maturity of watermelons. No single indicator is absolute for determining ripeness, because maturity differs with variety, location, and plant growth. It is better to use combination of these signs of maturity for better yield and quality.
Five to six weeks after pollination, depending upon variety and season, watermelons reach at harvest maturity. Different varieties may differ in certain characteristics that indicate maturity. A ripe watermelon can be identified just by glancing at the glossy rind surface. Other indications of ripeness include a change in the color of the ground spot from white to light yellow. A condition of the tendril (small curly stem attached to the fruit stem slightly above the fruit) can be a measurement of fruit ripeness. The change of tendrils from healthy green to brown as the tendrils dries showed that the fruits already mature and ripe. Thumping also is a reliable method to detect maturity in round-shaped watermelons. Fruit thumping, which produces a metallic ringing sound indicating immaturity and a more muffled or dull sound to indicate maturity or ripening. The best method is to cut a few watermelons in various section of the field and carefully associate ripeness with outward fruit appearance.

Several destructive methods can be used on randomly selected fruit to predict harvest maturity of the remaining fruit in the field of similar size. When the fruit is cut in half lengthwise, the entire flesh should be well-colored and uniform red to dark red (unless it is a yellow-flesh type). In addition, the flesh of mature fruit should be firm, crisp, and free of hollow heart. Immature melons have pink colored flesh and over-mature fruit have reddish-orange flesh. To avoid harvesting over-mature fruits, watermelons should be harvested before vines become withered. For seeded cultivars, fruit is mature when jellylike covering around the seed is gone and the seed coat is hard and either black or brown in color. A fruit with a lot of white seeds is not mature and not ready for harvest.

Harvesting and marketing green and immature watermelons reduces customer satisfaction and lessens the demand by the consumer. Sugar content of watermelon fruits does not increase after harvest; however, red color continues to develop after a slightly immature melon is picked. Total sugar content is an important quality parameter of sweet and flavorful watermelons. The sugar level can be determined easily using a hand refractometer by randomly sampling from different section of field. High quality watermelons should have a sugar content (measured as soluble solids) of 10% or more in the flesh near the center of the melon.
3.10. Harvesting and Handling

The first step in harvesting and handling is to confirm maturity of the watermelon. Watermelons are considered optimum for eating when their flesh mature to produce a sweet flavor, crisp texture, and deep red color. Usually, watermelons reach harvest maturity 5 to 6 weeks after pollination, depending upon variety and season. One way to determine field maturity before harvest is to cut a few melons randomly and test their sugar level using hand refractometer. High quality watermelons should have a sugar content of 10% or more in the flesh near the center of the melon. Mature watermelons must be harvested at the optimum stage of maturity and handled gently enough to avoid damage to ensure market quality. The fruits become fit for harvesting 30–40 days after anthesis. Watermelon should be harvested before vines become withered. There are some maturity indicators that can help to determine the maturity of watermelon. Tendrils or pigtails on vines nearest the fruit are wilting and have changed color from green to brown. The ground spot on the belly of the melon has changed from white to light yellow; The thumping sound change from metallic ringing when immature to a soft hollow sound when mature. The green band gradually break up as they intersect at the blossom end of the melon. Ribbed indentations, which can be felt with the fingertips occur along the elongated body. For harvesting technique, a sharp knife should be used to cut melons from the vines; melons pulled from the vine may crack open. Harvested fruit is windrowed to nearby roadways, often located 10 beds apart. A pitching crew follows the cutters and pitches the melons from hand to hand, then loads them in trucks to be transported to a shed. Melons should never be stacked on the blossom end, as excessive breakage may occur (Shrefler et al., 2012). Several precautions need to be followed when handling. Watermelons should be cut from the vine rather than pulled, twisted or broken off to reduce chances of stem decay. Pulling stems out provides an entrance for bacteria and fungi that can cause souring and can decay the internal flesh.

3.11. Grading, Packaging and Storage

Usually watermelon based on good and very good level of optimum internal quality, which means of level of sweetness and another aspect. Watermelons are graded according to their size for consumer demand in local market. However, watermelons should bisymmetrical and uniform in

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appearance. In labeling, it is mandatory that watermelon containers have the name (commodity), net weight, count, and country of origin.

For packaging, the surface of watermelon should be waxy and bright in appearance devoid of scars, sunburn, transit abrasions or other surface defects. The fruits are transported by road in bulk by stacking them on dried grass in trucks. For storage, watermelons can be stored for 14 days at 15°C. For short-term storage or transit to distant markets (>7 days), watermelons can be stored at 7.2°C with 85–90% relative humidity (NARI, 2003). They are subjected to chilling injury and lose flavor and color at temperature lower than 10°C and watermelon can also become decay and mainly black rot when stored at 10°C or lower. Holding watermelons for up to a week at room temperature can improve flavor and color. However, after several weeks at room temperature, they will have poor flavor and texture. On top of that, watermelons are sensitive to ethylene and should not be stored or shipped with product that emits ethylene.

4. COMMON INSECT PESTS OF WATERMELON AND ITS CONTROL

Watermelons are susceptible to attack by a variety of insect pest. These insect pests can cause severe injury to the leaves, stems, roots and fruit of watermelon. These attacks may result in decrease in the quality of the crop and could lead to undesirable productivity. Thus, these insect pest problems should be handled properly. These can be managed through manually or chemically (insecticide). In the following section, we are discussing several common insect pests affect the watermelon plant as well as their management or control of these pests using insecticidal, the most commonly practiced in Malaysia.

4.1. Aphids

Aphids, *Aphis gossypii* (Homoptera: Aphididae) can cause considerable damage by attacking the young shoot or growing part. Aphids are very small, slow moving soft-bodied insects that colonize the abaxial surface of the young leaves. This insect is characterized by the presence of 2 pipe-like cornicles on the dorsal end of the abdomen (Figure 1A). It feeds on the leaf by sucking the cell sap with its piercing mouthpart. As a result of the feeding, the leaf curls

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downwards and appears crinkled (Figure 1B). The whole shoot may be affected causing the plant to turn yellow and wilt. Many aphids produce wax from the glands on their bodies; aphids also secrete honeydew that encourages growth of sooty mould (Alford, 2007) which could cover the leaf surface and affects photosynthesis. However, aphids could lead to severe damage and loss by being vector to several viruses such as cucumber mosaic virus which reduce watermelon growth and yield. Severe infestation could be controlled by using selected insecticides, such as dimethoate or acetamiprid. In some cases, presence of the natural enemy ladybird beetle (Coleoptera: Coccinellidae) whose larvae feed on the aphids, could reduce infestation. Reflective mulch such as silver shine sheet used to cover the planting bed will help reduce or delay infestation in the early stages of plant growth by aphids because the light reflection interferes with their searching ability to locate the plants.

Figure 1(A) Aphids
Source: Wu (2016)

Figure 1(B) Aphis damage to watermelon
Source: Rick et al., (2016)

Figure 1(C) Thrip
Source: Aggie Horticulture (2016)

Figure 1(D) Armyworm (Spodoptera litura)
Source: Aggie Horticulture (2016)

Figure 1(E) Larvae of armyworm damage
Source: AgPest (2016)

Figure 1(F) Fruit fly (Bactrocera cucurbitae)
Source: Meyer et al., (2014)

Figure 1 (A-F). Common insect pests of watermelon.

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4.2. Thrips

The melon thrips, *Thrips palmi* (Thysanoptera: Thripidae) inhabit the young leaves and shoot, and are usually found on the underside of the leaves. This minute insect which measures less than 1 mm in length (Figure 1C), uses the mouthparts to rasp on the leaf surface and suck the oozing cell sap. The infestation causes the young shoot to crinkle and bunch-up, which eventually dry up leading to die-back. Infestation in the early growth stage of the plant may eventually lead to crop failure because production of flowers and fruitlets are affected. This insect needs to be controlled during early infestation as the population will build up rapidly, especially during dry weather. However, thrips can be difficult to control effectively with insecticides due to their feeding behavior, mobility, and protected egg and pupal stages (Bethke and Varela, 2014). Suitable insecticides, such as dinotefuran or spinosad, could be used to control this pest. Reflective mulch, such as silver shine sheet, has the same effect on thrips as with aphids. Bright yellow sticky traps hung near the plants could serve to monitor the thrips and also help to reduce thrips population.

4.3. Armyworm

The armyworm, *Spodoptera litura* (Lepidoptera: Noctuidae) attacks both the leaves and the fruits of watermelon. The armyworm has green body (Green caterpillar) with dark brown edges stripes over its green body (Figure 1D) (Redaksi AgroMedia, 2010). The larvae of this insect are ferocious eater, capable of devouring leaves of sizable area of the watermelon (Figure 1E). Damaged areas would be devoid of leaves leaving bare stems. Early infestation by this pest could lead to crop failure. The larvae also bore into and consume fruitlets and mature fruits causing severe loss of both fruit quality and yield. Chemical pesticides, such as fenvalerate or trichlorfon, could be used to provide immediate control. Fenvalerate does not affect pollinating bees. The use of nuclear polyhedrosis virus (NPV) to control the armyworm has also been advocated.
4.4. Fruit Fly

The melon fruit fly, *Bactrocera cucurbitae* (Diptera: Tephritidae) causes damage to young fruits. The female inserts (Figure 1F) its ovipositor into the fruit and deposits the eggs inside the rind. After hatching, the larva bores into the fruit and damages the inner part of the fruit. Control of melon fruit fly can be done using a trap that contains the sex attractant methyl eugenol, which attracts the male fly, and thereafter reduces the number of viable eggs laid. The methyl eugenol trap is usually mixed with a few drops of malathion, which kills the male fly attracted into the trap. Insecticidal control can be carried out where necessary by using suitable insecticides, such as spinosad or cypermethrin.

4.5. Ant and Grasshopper

Ant and grasshopper can cause damage by attacking the young seedlings of watermelon. These insects feed on the young seedlings until the plant is destroyed. As a result of the feeding, the young seedlings cannot be replanted. Both ant and grasshopper can be controlled by using insecticides containing active ingredients, such as Furadan 3G, Petrofus, and Curater.

5. Common Diseases of Watermelon and Its Control

Diseases are important factors in watermelon production. Certain diseases could cause failure of the crop if the environmental condition favors the development of these particular diseases. In the course of crop growth and production, the watermelon is subjected to environmental variations and changes that may precipitate into disease prevalence and cause losses. If disease control practices are neglected or not followed some loss can be expected to occur at each cropping season through leaf and stem diseases and other ailments.
5.1. Downy Mildew

Downy mildew is caused by *Pseudoperonospora cubensis*, an airborne fungus that attacks the leaves of watermelon. Lesions first appear on the older leaves as yellow, mottled spots which later coalesce into larger brownish yellow patches causing the leaves to curl inward toward the midribs (Figure 2A). Under favorable conditions, this disease progresses rapidly, resulting in a scorched appearance over the entire crop area that eventually leads to crop loss. Control of this disease can be initiated using fungicides, such as zineb, mancozeb, and chlorothalonil.
5.2. Powdery Mildew

Powdery mildew is caused by two types of fungi; *Sphaerotheca fuliginea* and *Erysiphe cichoracearum*. Symptom begins with a white to grey dusty material on the upper leaf surface (Figure 2B). These fungi will completely cover the leaf surface rapidly, resulting to crisp texture on the leaves and the

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plant will eventually die. Powdery mildew is favored by high relative humidity with no free water on the leaves. These fungi can be controlled using fungicides, such as pyraclostrobin, quinoxyfen, myclobutanil, and triflumizole.

5.3. Anthracnose

Anthracnose is caused by the fungus *Colletotrichum legenarium*, which attacks all above ground parts of the watermelon plant and at any stage of growth. Symptom begins with round to angular brown spots on the older leaves, which may later become dry, dark, and tear out, giving a ragged appearance to the leaves (Figure 2C). This disease can be destructive, especially after a few days of hot rainy weather in which every leaf can be infected and killed, giving the field a burnt appearance. Infected fruits have round sunken water-soaked pots, usually with pinkish colored ooze which is the spores of the anthracnose fungus (Figure 2D). Fungicides, such as chlorothalonil or benomyl, can be used to control this disease.

5.4. Gummy Stem Blight

The fungus *Didymella bryoniae* is responsible for the gummy stem blight of watermelon. This fungus can cause crown rot, stem canker, leaf spot, fruit rot, and damping-off of watermelons. Early infection usually comes from contaminated seed. Symptom of attack begins with irregular or round brown spots lesions on the cotyledons and leaves (Figure 2E). The brown spots are usually developed in the lobes of the leaves. Lesions on the stem and crown are brown and become white on the older plant. Under the favourable conditions, fungus *Didymella bryoniae* attacks vines, causing elongated, water-soaked areas that later become light brown to grey (Figure 2F). Older stems near the crown, usually near a leaf tendril or petiole, split and a light brown gum ooze from the water-soaked area. Infected plant usually dies one at a time. Old plant debris removed, crop rotation, and plant resistant species can prevent the gummy stem blight disease. Fungicides control can be carried out by using mancozeb, chlorothalonil, and strobilurin. Mancozeb and chlorothalonil are recommended to apply in rotation with strobilurin in order to prevent resistance to strobilurin in *Didymella bryoniae*.
5.5. Alternaria Leaf Spot

Alternaria leaf spot is caused by the fungus *Alternaria cucumerina*. Lesions first appear on the older leaves as round to irregular spots which later coalesce into large spots and concentric rings are developed in the lesions (Figure 2G). Under favorable condition; continuous wet, the disease progress rapidly. *Alternaria cucumerina* can be controlled with a two years no cucurbits planting rotation, destroy of the previous infected plant residue. Control of the disease can be carried out using fungicides such as chlorothanil, fludioxonil, imazalil, maneb, mancozeb, and iprodine.

5.6. Cercospora Leaf Spot

Cercospora leaf spot is caused by the fungus *Cercospora citrullina*. Symptom first appears on the crown of the plant with dark brown center and a yellow halo spots (Figure 2H). If disease developed severe without control, it can cause leaves loss, which then restrict fruit development and result in sunburn of watermelon fruit. Fungicides, such as myclobutanil, azoxystrobin, and mancozeb, can be used to control the disease.

5.7. Myrothecium Leaf Spot

This disease is caused by the fungus *Myrothecium roridum*. Symptom of attack includes small and dark brown circular lesions on leaves. The lesions later will coalesce into larger (Figure 2I). Under favorable condition; wet weather, the disease developed rapidly. The pathogen can be controlled by using fungicides, such as fludioxonil, chlorothabnil, triflumizole, and thiophanate-methyl.

5.8. Bacterial Fruit Blotch

The bacterium *Acidovorax avenae* subsp. *citrulli* causes fruit blotch of watermelon. Symptoms of infection include seedling blight, leaf lesions and fruit symptoms. Early symptoms in young watermelon seedlings appear as dark water soaking of the lower surface of cotyledons and leaves, which may later develop to necrotic lesions and frequently have chlorotic halos (Figure

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2J). The lesions can cause in collapse and death of the plant if disease control practices are neglected. The infected leaves have light brown to reddish-brown in color lesions and usually spread along the midrib of the leaves. Leave lesions in the plantation may not result in defoliation. However, treatment of the disease is important to prevent reservoirs of *Acidovorax avenae* subsp. *citrulli* for fruit infection. Fruit symptom begins with water-soaked spots which may later enlarge rapidly to become brown color, fruit crack, and a fruit rot may occur (Figure 2K). Mature fruit is more resistant to infection. However, once the disease has occurred, watermelon plant should not be replanted in the field for at least one season, the infected plant should destroy, and weeds management is also important to control the disease. Copper based fungicide, such as copper hydroxide, can be applied to treat the disease.

5.9. Leaf Mosaic

The watermelon mosaic virus causes mottling and mosaic pattern on the leaf. Affected plants become stunted with abnormal leaf shapes, shortened internodes, and bushy erect growth habit (Figure 2L). Infected fruits have a mottled appearance on the fruit surface. The virus is vectored by aphids. Control strategies include clean planting materials, destroy infected plants, and control of aphids.

5.10. Tobacco Ring Spot Virus

The tobacco ring spot virus causes tiny brown spots surrounded by yellow halo on young leaves of watermelon (Figure 2M). The virus is spread from infected plants by grasshopper, beetles, thrips, nematode, and other insects. This disease can be prevented through destroy infected plants and control insect pests.

5.11. Leaf Rot

Leaf rot disease is caused by the bacterium *Phytophthora infestans*. Infected watermelons have black spots appearance on the leave and fruit surface. The attacked area will be dried, harder, and eventually rotted (Figure 2N). Control humidity of the planted area and good cultural practices such as

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frequent pruning and hygiene of plantation are necessary in preventing rotten leaves disease of watermelon. Chemical control can be conducted by using 1–3% Bubur Bordeaux, Akofol 50 WP, Preficur N, Prufit PR 10/56 WP, Ridomil, Dhitane M-45, and Antracol.

5.12. Stem Rot

Stem rot is caused by the fungus *Botryodiplodia theobromae*. This disease attacks the stem and its branches. Infected area becomes brown in color and later the white mycelium of the fungus is formed on the rind. The lesions are then prone to stem rot disease. This disease can be prevented through land cleaning before planting and seed treatment. Fungicide, such as Delsene MX 200 or Derosal 500 SC, can be used to treat the disease.

5.13. Fusarium Wilt

The fungus *Fusarium oxysporum* f.sp. niveum causes fusarium wilt of watermelon. This fungal pathogen is soil borne and able to survive as chlamydospores in the soil for a long time. Symptom of attack includes a dull, grey green appearance of the leaves that precedes a loss of turgor pressure and wilting. The wilting is followed by a yellowing of the leaves and later necrosis (Figure 2O). If the inoculum density is high in the soil, the entire plant may wilt and die in a short time. Diagnostic symptom of Fusarium wilt is a brown discoloration of the vascular bundle in longitudinal or cross section of the stem or root. This disease once set in is difficult to control. Therefore, management of the disease include the use clean disease-free seeds for planting, the use of resistant varieties, and crop rotation. It is not advisable to plant watermelon continuously on the same area over a long period. Crop rotation with non-cucurbit type crops should be practiced to break the disease cycle. One novel method that is being practiced is the use of other cucurbit species such as *Cucurbita* spp and *Lagenaria* spp., which are resistant to *Fusarium oxysporum* f.sp. niveum as rootstocks for grafting, to control fusarium wilt of watermelon. However, this method is labor-intensive and expensive.
5.14. Bacterial Wilt

The bacterial Pseudomonas causes bacterial wilt of watermelon. This bacterial pathogen is spread by wind, water, and equipment. Symptom of attack is similar to Fusarium wilt. The attacked area will exude white substance. This disease is commonly occurring during favorable conditions; low land area and a few days of hot rainy weather. Similar to Fusarium wilt, this disease also can cause in death of watermelon plant. The attacked area is recommended to treat with agricultural lime (aglime) and do not plants with crops that can become host to bacterial Pseudomonas over 2-years period. Pesticides, such as Agrept 20 WP or Agrimycin 15/1.5 WP, can be used to treat the disease.

5.15. Damping-Off

Damping-off is a seedling disease (Figure 2P) that involves a complex of Pythium spp, Rhizoctonia spp. and Fusarium spp. The litter from previous crop may contribute toward the severity of this disease. Severe cases could drastically reduce the crop stand. Good cultural practices and seed treatment are necessary in preventing damping-off of young watermelon seedlings. Fungicide, such as benomyl, can be used to treat the disease.

5.16. Scab

Scab is caused by the fungus Cladosporium cucumerinum which attacks all above ground parts of the watermelon plant. This disease attacks both the young and mature plant. Scab can cause the most severe damage on watermelon fruit. The attacked fruit first appear to have brownish green spots and later may create a notch on the surface (Figure 2Q). A gummy white substance is exuded in drops from the infected area. The fungus Cladosporium cucumerinum also attacked watermelon leaves which may cause yellow spots appearance to the leaves. Management of the disease include the use resistant varieties, weed control, and crop rotation. In addition, control of the disease can be initiated using fungicides, such as Manzate or Ridomil MZ.
5.17. Blossom End Rot

This disorder is caused by calcium deficiency in the blossom end of the fruit. Symptom includes young fruit dropping off, and brown rotting lesions at the blossom end of older fruit (Figure 2R). Treatment with liming, good water management, and sufficient soil calcium availability will help address this disorder.

6. Food Value of Watermelon

Watermelon possesses high nutritional value and has rich bioactive compounds. Generally, watermelon flesh is consumed directly (Erhirhie and Ekene, 2013). Watermelon fruits are very juicy, with a moisture content of an approximately 93% (Tola and Ramaswamy, 2013). Watermelon juice is consumed as a popular thirst-quencher drink during hot summer weather. However, high water activity (0.97–0.99) and low acidity (pH 5.2–6.7) characteristics of watermelon juice could lead to the susceptible to microbial and oxidative enzymatic spoilage (Harris et al., 2003; Mosqueda-Melgar et al., 2008; Oberoi and Sogi, 2015). Reports are available wherein watermelon juice was processed by treating with high intensity pulsed electric fields (HIPEF) (35 kV/cm for 1,727 μs applying 4-μs pulses at 188 Hz in bipolar mode) (Aguiló-Aguayo et al., 2010) to maintain their quality and for preservation. As an output of the research, these researches summarized that HIPEF-treated juice maintained brighter red color juice and higher viscosity along the storage time (56 days). Moreover, peroxidase (POD) was inactivated more efficiently after HIPEF processing compared to thermal treatments (Aguiló-Aguayo et al., 2010).

In another report, watermelon juice was treated using combined treatment of mild heat and high pressure carbon dioxide treatment (Liu et al., 2012). Results showed the residual activity of enzyme (POD, polyphenoloxidase, and pectin methylesterase) decreased with pressure and treatment time after treated with heat and pressure carbon dioxide. The color of the product (browning degree) decreased with pressure and treatment time. Liu et al., (2012) concluded that combination treatment; mild heat and high pressure carbon dioxide has greater benefits to maintain the quality and extent the shelf life of watermelon juice.

Watermelon juice was transformed into powder by applying spray drying method to extent the shelf life and make available watermelon juice.
throughout the year (Quek et al., 2007). In the study, two different concentrations (3 and 5%) of maltodextrin (Dride 9) was used and it was processed at different inlet temperatures; 145, 155, 165, and 175°C. The authors found that the watermelon spray-dried powders have the best colorimetric results, desirable water activity and moisture content, as well as excellent lycopene and β-carotene content during processing at the inlet temperature of 155°C.

Oberoi and Sogi (2015) study the effect of different drying methods (spray drying or freeze drying) and maltodextrin concentration (3, 5, 7, and 10%) on physicochemical characteristics of watermelon juice powder. Their results showed spray dried powder has lower water activity, moisture content, reducing sugar content, and pigment retention (high ‘L’ value, low ‘a’ and ‘b’ value), but has higher dissolution value as compared to freeze dried powder. The moisture content of the watermelon juice powder (spray and freeze-dried powders) decreased while time for reconstituting and sugar content increased as increase in concentration of maltodextrin. Application of spray drying technique produces product with longer shelf life (Oberoi and Sogi, 2015).

Watermelon rinds are edible and contain many hidden nutrients, but are rarely eaten and usually discarded wholesome into the environment due their unpleasant flavor (Okareh et al., 2015). However, in China, watermelon rinds are commonly consumed as vegetable by stewing or stir-frying (Fila et al., 2013). According to Souad et al., (2012), watermelon waste materials particularly the rinds remain as one of the important food grade agro-wastes generated by many food industries across Southeast Asia and particularly in Malaysia. It is a known fact that fruit peel generates considerable amount of food waste, but surprisingly, this waste has more, or as much, nutrition, as the inner flesh portion. Many times, people discard parts of fruits that they consider inedible. Not only is this a habit wasteful, but it also means that people are missing out on health benefits they never before considered (Michelle, 2014).

The rind is utilized only in small quantities for food production such as pickles, candy, anvadiyam, cheese, and fruit butter (Simonne et al., 2002; Madhuri and Devi, 2003; Yadla et al., 2013; Muhamad et al., 2015). According to Mandel et al., (2005), pickled watermelon rind is commonly consumed in the Southern United States. Watermelon rind contribute 35% of the total weight, it can be converted into value added product (Souad et al., 2012) by drying or processing into flour. Watermelon rind flour can be used as a functional ingredient for the preparation of bakery products which often contain low nutritional value and fiber content.
Impregnation of anthocyanins from kokum (*Garcinia indica* Choisy) into watermelon rind by employing osmotic treatment has been demonstrated by Bellary et al., (2016). The authors reported watermelon rind candy was highly acceptable among panelists in sensory evaluation for the attributes: appearance, taste, and texture. In addition, the watermelon candy was stable in terms of moisture content, appearance, texture, taste, and anthocyanin degradation during storage in low density polyethylene pouches or polyethylene terephthalate/low density polyethylene pouches for 90 days at ambient temperature.

There has also been a study conducted on the possible use of the watermelon rinds as a natural source of pectin. According to Yapo et al., (2014), watermelon rind pomace is a highly rich pectin source and thereby possesses the potential for utilization as raw materials for the possible production of marketable high methoxy pectins. The possibility of utilizing watermelon rind flour in noodles, jams, and other baked foods has been investigated by different workers (Bhatnagar, 1991; Madhav and Pushpalatha, 2002; Souad et al., 2012; Hoque and Iqbal, 2015; Ho and Dahri, 2016).

Watermelon seeds are a very good source of protein and fat (Liu et al., 2011). In Arabian countries, watermelon seeds are used directly for human consumption as snacks after roasting and salting (Al-Khalifa, 1996). In addition, watermelon seeds oil has been processed to cooking oil in Middle East and West Africa countries such as Nigeria (Akoh and Nwosu, 1992). According to El-Adawy and Taha (2001), the seeds of watermelon have been used as food additives.

### 7. COMPOSITION AND NUTRITIONAL VALUE

The composition of fresh watermelon pulp (per 100 g edible portion) includes: 91.45% water (moisture), 0.61% protein, 0.15% fat, 0.4% dietary fiber, 7.55% carbohydrate, and 30 kcal energy (USDA, 2016). Al-Sayed and Ahmed (2013) evaluated the proximate composition of watermelon rind flour. They found that watermelon rind contains 10.61% moisture, 13.09% ash, 2.44% fat, 11.17% protein, 17.28% dietary fibre, 56.00% carbohydrates, and 290.64 kcal energy (on dry weight basis). Further, proximate analysis of defatted watermelon seed flour revealed that it contains: 3.8% moisture, 0.95% fat, 61.29% protein, 5.21% ash, 9.50% crude fiber (Lakshmi and Kaul, 2011), 28.75% carbohydrate, and 368.71 kcal energy. However, El-Adawy and Taha (2001) detected watermelon seed flour had more fat (crude fat: 50.10 g/100g

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... dry weight sample) content than the results reported by Lakshmi and Kaul (2011). Table 1 shows the summary of the proximate composition of watermelon pulp (on fresh weight basis), rind (on dry weight basis), and defatted seed flour (on dry weight basis).

Watermelon pulp have a very good source of calcium (7 mg/100 g), iron (0.24 mg/100 g), magnesium (10 mg/100 g), phosphorus (11 mg/100 g), and potassium (112 mg/100 g) (on fresh weight basis) (USDA, 2016). Watermelon seed flour contained considerable amounts of minerals with the exception of copper (El-Adawy and Taha, 2001). E-Adawy and Taha (2001) found watermelon seed flour contains 1,279 mg/100 g phosphorus, 1,176 mg/100 g potassium, 542 mg/100 g magnesium, 150 mg/100 g calcium, 33 mg/100 g sodium, 12.1 mg/100 g iron, 10.6 mg/100 g zinc, 9.9 mg/100 g manganese, and 2.1 g/100 g copper (Table 2).

Table 1. Proximate composition of watermelon pulp, rind, and defatted seed flour

<table>
<thead>
<tr>
<th>Compound</th>
<th>Amount</th>
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</thead>
<tbody>
<tr>
<td>Proximate composition (on fresh weight basis; g/100 g) of watermelon pulp</td>
<td></td>
</tr>
<tr>
<td>Water (Moisture)</td>
<td>91.45</td>
</tr>
<tr>
<td>Protein</td>
<td>0.61</td>
</tr>
<tr>
<td>Total lipids (fat)</td>
<td>0.15</td>
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<td>Dietary fiber</td>
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</tr>
<tr>
<td>Carbohydrate</td>
<td>7.55</td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>30.0</td>
</tr>
<tr>
<td>Proximate composition (on dry weight basis; per 100 g) of watermelon rind flour</td>
<td></td>
</tr>
<tr>
<td>Water (Moisture)</td>
<td>10.61</td>
</tr>
<tr>
<td>Fat</td>
<td>2.44</td>
</tr>
<tr>
<td>Protein</td>
<td>11.17</td>
</tr>
<tr>
<td>Ash</td>
<td>13.09</td>
</tr>
<tr>
<td>Crude fiber</td>
<td>17.28</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>56.00</td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>290.64</td>
</tr>
<tr>
<td>Proximate composition (on dry weight basis; per 100 g) of watermelon defatted seed flour</td>
<td></td>
</tr>
<tr>
<td>Water (Moisture)</td>
<td>3.8 ± 0.01</td>
</tr>
<tr>
<td>Fat</td>
<td>0.95 ± 0.15</td>
</tr>
<tr>
<td>Protein</td>
<td>61.29 ± 0.17</td>
</tr>
<tr>
<td>Ash</td>
<td>5.21 ± 0.13</td>
</tr>
<tr>
<td>Crude fiber</td>
<td>9.50 ± 0.00</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>28.75</td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>368.71</td>
</tr>
</tbody>
</table>

Source: Lakshmi and Kaul (2011); USDA (2016).
Table 2. Minerals of watermelon pulp, and defatted seed flour

<table>
<thead>
<tr>
<th>Component</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minerals (dry weight basis; mg/100g) of watermelon pulp</td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>7.0</td>
</tr>
<tr>
<td>Iron</td>
<td>0.24</td>
</tr>
<tr>
<td>Magnesium</td>
<td>10.0</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>11.0</td>
</tr>
<tr>
<td>Potassium</td>
<td>112.0</td>
</tr>
<tr>
<td>Minerals (dry weight basis; mg/100g) of watermelon defatted seed flour</td>
<td></td>
</tr>
<tr>
<td>Phosphorus</td>
<td>1,279</td>
</tr>
<tr>
<td>Potassium</td>
<td>1,176</td>
</tr>
<tr>
<td>Magnesium</td>
<td>542</td>
</tr>
<tr>
<td>Calcium</td>
<td>150</td>
</tr>
<tr>
<td>Sodium</td>
<td>33</td>
</tr>
<tr>
<td>Iron</td>
<td>12.1</td>
</tr>
<tr>
<td>Zinc</td>
<td>10.6</td>
</tr>
<tr>
<td>Manganese</td>
<td>9.9</td>
</tr>
<tr>
<td>Copper</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Source: El-Adawy and Taha (2001); USDA (2016)

Sugar composition in watermelon fruits has been reported. According to Leskovar et al., (2004), fructose and glucose contents increased with low amount of water supply/irrigation (0.5 and 0.75 ET (Estimated Consumptive Use)) compared with 1.0 ET. In addition, the partitioning of the significant irrigation rate and cultivar interaction for sucrose demonstrated that the disaccharide sucrose was reduced with deficit irrigation (0.5 ET). Further, watermelon fruit pulp has significant amounts of glucose, fructose, and sucrose. Red, yellow, and orange fleshed watermelon cultivars were generally found to have more fructose than glucose or sucrose (Perkins-Veazie et al., 2002). The authors concluded that total sugar did not decrease with deficit irrigation at 0.75 ET.

Lakshmi and Kaul (2011) studied the nutritional content, bio-accessibility of minerals, and functionality of watermelon seeds. The authors reported that watermelon seeds contain high in protein and fat. They found that in vitro digestibility of the protein was excellent with less of anti-nutritional factors. Anti-nutritional compounds, such as phytic acid (2.63 g/100 g dry weight flour), trypsin inhibitor (1.46 Trypsin Inhibitor Unit (TIU)/mg protein), stachyose (0.67 g/100 g dry weight flour), raffinose (0.32 g/100 g dry weight flour), verbascose (0.26 g/100 g dry weight four), and tannins (0.24 g/100 g dry weight flour), were found to be presented in watermelon seed kernel flour.

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(El-Adawy and Taha, 2001). The percent bio-accessibility of calcium, zinc, and iron were found to correlate ($R^2 = 0.97–0.99$) with the concentration of tannin, oxalate, and phytate contents in watermelon seed flour. (Lakshmi and Kaul, 2011). Badifu (2011) reported that watermelon seeds contain very excellent edible value and have a very few toxic factors and anti-nutritional compared to the other general of Cucurbitaceae.

Johnson et al., (2013) reported on the vitamin composition of fresh and dried watermelon (pulp, seeds, and rind). They found watermelon rind contains superior vitamin as compared to watermelon seed and pulp (Table 3). The fresh fruits generally were low in carotenoid (pro-vitamin A) though that of the rind was higher compared with other parts of the fruit. Ascorbic acid (vitamin C) content of the fresh and dried pulp was higher compared with the seed and rind. In addition, the authors found that watermelons (pulp, seed, and rind) were low in vitamins B (thiamine, riboflavin, and niacin) (Johnson et al., 2013). Logaraj (2011) concluded a totaling of $3.8\,\text{mg}\,\text{B}\,\text{vitamins}\,\text{(thiamine, riboflavin, niacin, folate, pantothenate, and pyridoxine)}$ in 31 g of seed is equivalent to 19% of the daily requirement. Mélo et al., (2006) reported watermelon fruit flesh to contain $57.62\,\mu\text{g}\,\beta\text{-carotene/g}\,\text{fresh weight ascorbic acid}$. According to Johnson et al., (2013), the nutrients contained within the rind, which are often discarded, can contribute immensely to recommended daily allowance and maintenance of good nutritional balance and hence beneficial for both man and animals alike.

El-Adawy and Taha (2001) studied on protein composites of watermelon seed kernel flour. The authors found that the protein composites of the seeds are mostly of amino acid; 18 amino acids, which dominantly consisted of 9 essential amino acids and 9 non-essential amino acids. The detected amino acids in watermelon seed kernel flour includes: isoleucine ($2.8\,\text{g/16}\,\text{g}\,\text{nitrogen}$), leucine ($7.7\,\text{g/16}\,\text{g}\,\text{nitrogen}$), lysine ($3.14\,\text{g/16}\,\text{g}\,\text{nitrogen}$), methionine ($1.71\,\text{g/16}\,\text{g}\,\text{nitrogen}$), phenylalanine ($5.76\,\text{g/16}\,\text{g}\,\text{nitrogen}$), threonine ($3.09\,\text{g/16}\,\text{g}\,\text{nitrogen}$), tryptophan ($1.15\,\text{g/16}\,\text{g}\,\text{nitrogen}$), valine ($3.98\,\text{g/16}\,\text{g}\,\text{nitrogen}$), histidine ($3.21\,\text{g/16}\,\text{g}\,\text{nitrogen}$), cysteine ($1.39\,\text{g/16}\,\text{g}\,\text{nitrogen}$), tyrosine ($3.92\,\text{g/16}\,\text{g}\,\text{nitrogen}$), arginine ($18.6\,\text{g/16}\,\text{g}\,\text{nitrogen}$), serine ($5.01\,\text{g/16g}\,\text{nitrogen}$), proline ($4.12\,\text{g/16}\,\text{g}\,\text{nitrogen}$), glycine ($5.66\,\text{g/16}\,\text{g}\,\text{nitrogen}$), alanine ($5.07\,\text{g/16}\,\text{g}\,\text{nitrogen}$), aspartic acid ($8.09\,\text{g/16}\,\text{g}\,\text{nitrogen}$), and glutamic acid ($15.6\,\text{g/16}\,\text{g}\,\text{nitrogen}$). According to Nwokolo and Sim (1987), watermelon seed kernel flour is superior to soybean due to present of all amino acids except lysine. Therefore, watermelon seed kernel flour requires supplementation with complementary protein if they are to be used as food sources (El-Adawy and Taha, 2001).
Table 3. Vitamin contents of fresh and dried watermelon

<table>
<thead>
<tr>
<th></th>
<th>Carotene (μg/100 g)</th>
<th>Thiamine (mg/100g)</th>
<th>Riboflavin (mg/100g)</th>
<th>Niacin (mg/100g)</th>
<th>Ascorbic acid (mg/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fresh watermelon</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulp</td>
<td>15.73 ± 0.17</td>
<td>0.09 ± 0.00</td>
<td>0.03 ± 0.00</td>
<td>0.02 ± 0.00</td>
<td>9.39 ± 0.59</td>
</tr>
<tr>
<td>Seed</td>
<td>0.00 ± 0.00</td>
<td>0.13 ± 0.00</td>
<td>0.13 ± 0.02</td>
<td>3.22 ± 0.00</td>
<td>5.28 ± 0.00</td>
</tr>
<tr>
<td>Rind</td>
<td>76.91 ± 0.01</td>
<td>0.14 ± 0.00</td>
<td>0.00 ± 0.00</td>
<td>0.06 ± 0.01</td>
<td>7.63 ± 0.59</td>
</tr>
<tr>
<td><strong>Dry watermelon</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulp</td>
<td>57.25 ± 0.42</td>
<td>0.06 ± 0.00</td>
<td>0.02 ± 0.00</td>
<td>0.01 ± 0.00</td>
<td>4.11 ± 0.59</td>
</tr>
<tr>
<td>Seed</td>
<td>0.00 ± 0.00</td>
<td>0.11 ± 0.01</td>
<td>0.12 ± 0.00</td>
<td>2.97 ± 0.01</td>
<td>2.35 ± 0.59</td>
</tr>
<tr>
<td>Rind</td>
<td>169.58 ± 0.17</td>
<td>0.13 ± 0.01</td>
<td>0.00 ± 0.00</td>
<td>0.05 ± 0.00</td>
<td>2.93 ± 0.59</td>
</tr>
</tbody>
</table>

Source: Johnson et al., (2013).

El-Adawy and Taha (2001) reported on the fatty acid composition of watermelon seed flour. Watermelon seed kernel oil contains 78.4% total unsaturated fatty acids, 21.7% total saturated fatty acids, 18.4% monounsaturated fatty acids, and 60.0% polyunsaturated fatty acids (El-Adawy and Taha, 2001). They recorded dominant unsaturated fatty acid to be: linoleic (59.6%) and oleic acids (18.1%) and other considerably lesser amounts of fatty acids also presented such as myristic (0.11%), palmitic (11.3%), palmitoleic (0.29%), stearic (10.2%), and linolenic (0.35%). According to Logaraj (2011), watermelon seeds offer approximately 600 calories and 79% of the recommended daily allowance of fat. In addition, the contents of watermelon seed kernel lipid could be fractionated into seven classes including triglycerides (94.9%), a major lipid class, free fatty acids (1.41%), sterols (1.12%), monoglycerides (0.98%), phospholipids (0.96%), diglycerides (0.35%), and hydrocarbons (0.27%) (El-Adawy and Taha, 2001).

Ziyada and Elhussien (2008) reported that oil extracted from watermelon (Citrullus lanatus var. Colocynthis) seed exhibited high stability (PV value: 4.76 meq/kg) against oxidation due to a low concentration of phosphorus (lower refining losses) and trace elements compared to other edible vegetable oils, such as cotton seed, groundnut, and sunflower seed oil. In addition, watermelon seed oil showed high degree of unsaturation and fatty acid composition. The edibility of the oil obtained from watermelon seed can be proved by the infrared spectrum, which is typical of the vegetable edible oil (Ziyada and Elhussien, 2008).

Later, the yield of the watermelon seed oil was successfully improved by employing aqueous enzymatic methods and ultrasonic as a pre-treatment technique (Liu et al., 2011). Accordingly, the authors reported that under the
optimal aqueous enzymatic hydrolysis conditions (temperature 47.13°C; time 4.29 hours; solid to solvent 1:4.35; pH 7.89; enzyme additive amount (protex) 2.63%), the oil extraction efficiency reached 77.25%. However, the oil extraction efficiency increased to 98.64% after ultrasonic treatment at optimal level of ultrasonic power: 547 W; ultrasonic temperature: 48°C; ultrasonic time: 23 s.

Further, watermelon seed components demonstrated excellent functionality include: water absorption capacity, fat absorption capacity, emulsification capacity, emulsification stability, emulsification activity, and foam capacity (2.55 g water/g flour, 3.89 mL oil/g flour, 98.2 mL oil/g protein, 44.1%, 60.0%, and 18.1% volume increase, respectively) were presented excellent in watermelon seed kernel flour (El-Adawy and Taha, 2001). In another report, watermelon seed flour was determined for functional properties (Lakshmi and Kaul, 2011). Results showed watermelon seed flour to have higher capacity to absorb water (3.33 mL water/g flour) than oil (2.35 mL oil/g flour).

With regard to watermelon rind product, 100 g of the edible portion (fresh weight basis) of \textit{Saccharomyces cerevisae} fermented watermelon rind has been reported (Erukainure et al., 2010) to contain: moisture (87.06 g), ash (1.61 g), lipid (0.81 g), protein (2.80 g), crude fiber (1.78 g), and carbohydrate (5.94%). Erukainure et al., (2010) revealed a decrease in the anti-nutrient contents (tannin, oxalate, and phytic acid) and phytonutrients (alkaloids and saponin), however, an increase in the phenolic and flavonoid contents of the fermented watermelon rinds as compared with unfermented watermelon rinds.

\section{8. Phytochemicals}

Reports available have shown watermelon (pulp, rind, and seed) to encompass a wide array of natural phytochemical components. Abu-Reidah et al., (2013) characterized the phytochemical fraction (phenolic and other polar compounds) of watermelon-fruit-pulp extract by using high-performance liquid chromatography coupled with electrospray-quadrupole-time-of-flight mass spectrometry (HPLC-ESI-QTOF-MS). The authors identified 71 polar compounds present in a hydro-methanolic extract of watermelon, which mainly phenolic acids, flavonoids, lignin, iridoids, coumarins, and other phenolic derivatives.

Several carotenoids are well known to have health promoting activity, and watermelon can be a very vital source of lycopene and other carotenoids.
Watermelon juice is proven to be a very concentrated source of carotenoid, namely lycopene. Mélo et al., (2006) reported watermelon fruit flesh to contain 40.09 mg μg β-carotene/g fresh weight total carotenoids. A study of Edwards et al., (2003) shows the lycopene concentration of watermelon is 4,868 μg/100 g. Liu et al., (2012) reported that lycopene content of the watermelon juice was slightly decreased after treated with combination treatment of mild heat and pressure carbon dioxide. Perkins-Veazie et al., (2007) conducted the clinical assays of human plasma after watermelon ingestion by the subjects. Results indicated that lycopene was as bio-available from watermelon juice.

Katherine et al., (2008) extract lycopene from watermelon pulp by using supercritical CO\(_2\) (SC-CO\(_2\)) could serve as a food grade source of carotenoid. Results showed freeze-dried watermelon extracted with SC-CO\(_2\) at 70°C, 20.7 MPa, and 15% by volume ethanol yielded 38 μg/g fresh weight of lycopene. However, fresh watermelon fruit (non-freeze-dried) yielded higher lycopene amount (103±6 μg/g fresh fruit weight) than the freeze-dried watermelon (Katherine et al., 2008). Katherine et al., (2008) found that freeze-dried watermelon pulp loses lycopene across period of storage time.

Further, watermelon is also an excellent source of vitamin C and a source of vitamin A, notably through its β-carotene content. Carotenoids are widely believed to protect human health due to their antioxidant properties. Lycopene is a vibrant red tetraterpenic carotenoid with molecular formula of C\(_{40}\)H\(_{56}\) (Fuhrman et al., 2000; Lin and Chen, 2003). Seeded watermelon were recorded to have less lycopene than seedless (>50 μg/g fresh weight) ones (Perkins-Veazie et al., 2001).

A study was conducted by Leskovar et al., (2004) to explore the effects of deficit irrigation on chemical compositions (vitamin C, sugar composition, and lycopene content) of red-fleshed diploid (‘Allsweet’ ‘Summer Flavor 710,’ ‘Sugarlee,’ ‘SWD7302,’ and ‘RWM 8036’) and triploid (‘Tri X Sunrise,’ ‘Sugar Time,’ ‘Summer Sweet 5244,’ and SWT8706’) watermelon. Results revealed that total amount of irrigation had significantly affecting the yield of watermelon; where, plant irrigated at an amount water 395 mm for 1.0 ET rate had higher yield (53.9 metric ton/hectare) compared with total water applied at 173 mm for 0.5 ET (26.8 metric ton/hectare). Moreover, different cultivars can influence their yields, Triploids had a 34% higher total yield and fewer culls (2%) compared with diploid cultivars (25%). Highest soluble solids were obtained for ‘Sugar Time’ (13.4%). Lycopene content increased slightly with maturity (55.8 to 60.2 μg/g fresh weight), and was significantly highest (62.4 μg/g fresh weight) at 0.75 ET irrigation. Lycopene content averaged over all
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...treatments was 60–66 μg/g fresh weight for triploids and 45–80 μg/g for diploid fruits. Overall, lycopene and vitamin C content did not decrease with deficit irrigation at 0.75 ET.

Perkins-Veazie et al., (2001) found that lycopene content differs among 11 red-fleshed watermelon cultivars, with four cultivars having average content of >65.0 μg/g fresh weight. Moreover, seedless watermelon fruits having higher mean values of lycopene than seeded watermelon fruits. According to several available reports, the lycopene content in commercial watermelons was 45.1–53.2 μg/g fresh weight (Heinonen et al., 1989; Tee and Lim, 1991; Mangels et al., 1993). According to Vogele (1937), factors such as soil fertility, vine health, light intensity, day or night temperatures, irrigation, and harvest maturity could influence the synthesis of lycopene in watermelon. Perkins-Veazie et al., (2001) reported that watermelons (‘Sangria’) grown in Mexico and harvested on February (winter harvest) had a higher lycopene content than watermelons harvested on July (summer harvest), however, the opposite was observed in cultivar ‘Summer Sweet 5244.’

Watermelon is a natural and rich source of citrulline, a polar compound and a naturally occurring non-essential protein amino acid (Rimando and Perkins-Veazie, 2005). Watermelon (pulp and rind) contains a considerably high amount of citrulline, an arginine precursor and a metabolic intermediate in the nitric oxide cycle that has been proven to provide significant health benefits to heart, circulatory and immune systems (Nissinen et al., 2003). In an earlier report, 14 watermelon cultivars were found to contain from 0.42 to 1.83 mg/g fresh weight of citrulline, with an average content of 1.5 mg/g (Rimando and Perkins-Veazie, 2005). Citrulline is presented in all parts of the watermelon fruit (Collins et al., 2007) but watermelon rinds generally contain more citrulline than the flesh on a dry weight basis (24.7 and 16.7 mg/g dry weight, respectively). This results were in agreement with a study done by Tarazona-Díaz et al., (2011), they recorded that watermelon rind (3.34 g/kg fresh weight) had higher content of the amino acid citrulline than pulp (2.33 g/kg fresh weight). In another report by Perkins-Veazie et al., (2007), they found that citrulline content was similar among pulp colors, ripeness stages, and genotypes. The flesh, rind, and peel of watermelon was reported to contain 1.1, 1.0, and 1.5 mg of citrulline/g fresh weight, respectively.

Rimando and Perkins-Veazie (2005) reported citrulline content of watermelon ranged from 3.9 to 28.5 mg/g dry weight and was similar between seeded and seedless types (16.6 and 20.3 mg/g dry weight, respectively). Furthermore, red flesh watermelons had slightly less citrulline than the yellow or orange flesh watermelons (7.4, 28.5, and 14.2 mg/g dry weight,
respectively). Rind contained more citrulline than flesh on a dry weight basis (24.7 and 16.7 mg/g dry weight, respectively) but a little less on a fresh weight basis (1.3 and 1.9 mg/g fresh weight, respectively). These results indicate that watermelon rind, an underutilized agricultural waste, offers a source of natural citrulline (Rimando and Perkins-Veazie, 2005).

In addition, watermelon rinds also contain other phytochemicals, such as saponins, phenol, flavonoids, and alkaloids. These phytochemicals have biological effects such as anticancer, anti-diabetic, and anti-inflammatory properties, which can be used for therapeutic treatment or pharmacological production of drugs reducing the risk of chronic disease and to meet nutrient requirements for optimum health (Liu, 2004; Okafor et al., 2015). According to Okafor et al., (2015), watermelon rind has a potential to be used as food and/or drugs in ethno medication as they offer pharmacologic and dietary benefits. It is also possible to simply juice just the rind but no commercial uses for this juice have been noted till today.

8.1. Polyphenolic Compounds

According to Tlili et al., (2011), phenolic compounds could be the principal hydrophilic compounds contributing to the hydrophilic anti-oxidant activity in watermelon. Different watermelon cultivars of some maturity and ripening stage (white, white-pink, pink, and red-ripe) are reported to contain varied concentrations of total phenolic content and antioxidant capacities. At the ripeness stage (red-ripe), P503 cultivar exhibited the highest concentration of lycopene (64.5 mg/kg fresh weight), whereas Dumara cultivar presented the highest concentration of β-carotene (2.1 mg/kg fresh weight), Giza cultivar contains highest level of total phenol (260.1 mg GAE/kg fresh weight), flavonoid (260.0 mg RE/kg fresh weight) and total vitamin C (204.0 mg/kg fresh weight) (Tlili et al., 2011). Tlili et al., (2011) reported ripening stage strongly influenced β-carotene and lycopene contents, as well as the lipophilic antioxidant activity (LAA). Trolox equivalent antioxidant capacity (TEAC) assay showed that LAA has good correlations with lycopene and β-carotene contents ($R^2 = 0.649$ and 0.403, respectively). However, the hydrophilic antioxidant activity (HAA) only correlated to the amount of total phenols and flavonoids.

In another report, Tarazona-Díaz et al., (2011) found that watermelon rind (458 mg chlorogenic acid equivalent/kg fresh weight) had a moderate total phenolic content higher than that of the pulp (389 mg chlorogenic acid
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equivalent/kg fresh weight). The concentration of total phenolic compounds in watermelon fruits pulp was 9.81 mg catechin/100 g fresh weight, which represented the low phenolic content group (<100 mg catechin/100 g) (Mélo et al., 2006). The total flavonol content of the watermelon investigated by Mélo et al., (2006) had 0.71 mg quercetin/100 g fresh weight, whereas total proanthocyanidins and total anthocyanins were not detected.

8.2. Antioxidant Capacity

Watermelon fruit is indeed a rich source of known and characterized antioxidant molecules such as lycopene, a carotenoid known for its highly effective antioxidant owing to its ability to act as a powerful oxygen radical scavenger (Perkins-Veazie et al., 2002; Leskovar et al., 2004; Perkins-Veazie and Collins, 2006; Perkins-Veazie et al., 2007) may reduce the incidence of certain cancers (Perkins-Veazie et al., 2001). Raw watermelon fruits were found to contain a good amount of vitamin C; 9.6 mg/100 g fresh weight (USDA, 2003). Similar to lycopene, vitamin C is another antioxidant that assists to reduce the risk of several diseases, such as atherosclerosis, cataracts, cancer, and osteoarthritis (Leskovar et al., 2004). Tarazona-Díaz et al., (2011) found that watermelon rind and pulp to contain total antioxidant 46.96 and 43.46 mg ascorbic acid equivalent antioxidant capacity/kg fresh weight, respectively.

With regard to watermelon fruit juice, Oseni and Okoye (2013) reported that juice contains important carotenoids such as carotene and beta-carotene which are important in neutralizing free radicals in the body. Watermelon is a rich natural source of lycopene, a carotenoid of great interest because of its antioxidant capacity and potential health benefits (Rhodes and Zhang, 1999). Recently various techniques such as hydrothermal, thermosonication, supercritical fluids, and carbon dioxide were applied to extract bioactive compounds from watermelon (Katherine et al., 2008; Rawson et al., 2011; Liu et al., 2012). Kim et al., (2014) evaluated the antioxidant activity of hydrothermal extracts of different parts of watermelon (pulp, white rind, and green rind). Each parts of watermelons was extracted at different temperatures (100, 150, 200, 250, and 300°C) for different extraction times (10, 30 or 60 min). Generally, the antioxidant activity of three parts of watermelon increased with increase in treatment temperature and time (Kim et al., 2014). Further, the authors reported total phenol content (7,626.52 μg gallic acid equivalents (GAE)/g) was abundantly presented in green rind extracted via the
hydrothermal at 300°C for 30 min as compared with untreated green rind extract (715.15 μg GAE/g). Several bioactive compounds such as catechol, pyrogallol, 1,2,4-benzenetriol, and 4-methylcatechol were identified in the watermelon parts (pulp, white rind, and green rind) (Kim et al., 2014).

Oberoi and Sogi (2015) found fresh watermelon juice to contain 4.58–6.53 mg/100 g fresh weight lycopene. The amount of lycopene could be increased by applying drying method where: content of lycopene (4.58–6.53 mg/100 g on fresh weight) of fresh watermelon juice was increased to 56.4 mg/100 g and 62.3 mg/100 g fresh weight after spray drying and freeze drying, respectively.

Citrulline is also an efficient hydroxyl radical scavenger and is a strong antioxidant (Akashi et al., 2001; Fang et al., 2002). Citrulline may protect leaves from drought-induced oxidative stress by acting as a hydroxyl radical scavenger (Akashi et al., 2001). However, little is known about the activity of citrulline in acting as a free radical scavenger. Therefore, more study is required on the ability of citrulline to act as a free radical scavenger from watermelon fruits (pulp, rind, and seed) in order to search for its suitability as a functional ingredient in developing drinks, juices or other food products with health promoting properties. Perkins-Veazie et al. (2007) determine the citrulline levels in the human plasma from the volunteers who consumed watermelon juice. Results showed that plasma levels of citrulline were highest in volunteers who ingested six cups of watermelon juice a day.

Recent research also shows that the watermelon rinds are important sources of natural antioxidants (Al-Sayed and Ahmed, 2013). Nowadays, cake manufacturers face a major problem of lipid oxidation which limits the shelf life of their products (Lean and Mohamed, 1999). Bakery products such as cakes with particularly those with high lipid content tend to become rancid after prolonged storage owing to the oxidation of polyunsaturated fatty acids (Ray and Husain, 2002; Smith et al., 2004). Special attention has given to the use of natural antioxidants because of the current worldwide trend to avoid or minimize use of synthetic food additives (Kings and Berger, 2001). A study conducted by Al-Sayed and Ahmed (2013), showed that the peroxide value and acid value of cakes containing substituted flour made with different levels of watermelon rind were found to slow down the rate of peroxide and fatty acid formation, indicating the potency of antioxidants in watermelon rinds inhibiting lipids oxidation and hydrolysis, and the formation of peroxides and free fatty acid.
9. Pharmacological Properties

Watermelon is popular in indigenous system of folk medicine and it is known to contain bioactive compounds, such as cucurbitacin, triterpenes, sterols, alkaloids, vitamins, and minerals (Erhirhie and Ekene, 2013). The watermelon contains various nutrient compounds, such as ascorbic acid, β-carotene, citrulline, and lycopene, and they show significant protective effect against carbon tetrachloride-induced toxicity (Altas et al., 2011). Tong and Barbul (2004) reported the amino acids; citrulline and arginine for their usefulness in immune function, wound healing, sickle cell anemia, and cardiovascular health.

Jiyun et al., (2011) conducted a study on anti-diabetic potential of watermelon. Result of the study shows that watermelon has beneficial effect on diabetic. In addition, Swapnil et al., (2011) and Sharma et al., (2011) reported that the aqueous fruit pulp of extract of watermelon has a significant laxative activity. Furthermore, Francis et al., (2013) reported that watermelon juice has significance effect in Indomethacin-induced gastric ulceration. Additionally, amino acid composition (high arginine content, 18.6 g/16 g nitrogen) of watermelon is an indicative of the possession of the medicinal benefits (El-Adawy and Taha, 2001), which is often used to treat cardiac ailments and regulate blood pressure (Logaraj, 2011).

According to Logaraj (2011), watermelon seed oils have therapeutic values due to the presence of triglycerides and saturated and saturated fatty acids. Moreover, the seed tea was found to contain anti-helminthetic, laxative, and mildly diuretic effects, thus, it is effective in the treating dropsy and renal stones. Medicinally, watermelon fruit can help to prevent erectile dysfunction, acting as an antioxidant and treating jaundice, giardiasis, and enlarged liver (Hassan et al., 2011; Figueroa et al., 2012). It also has anti-carcinogenic properties at the concentration of the epithelial cells of glands. The dominant composition of the watermelon seed oil is ω-6 unsaturated fatty acids (linoleic acid), hence it helps to regulate blood pressure by dilating capillaries, especially in senile, post-menopausal, and obesity associated hypertension and decreasing the cholesterol levels (Logaraj, 2011). Seed oil of watermelon exhibited a very good nutritive as well as therapeutic and clinical activities that could be exploited in its apply as an effective nutraceutical.

Watermelon seeds are reported to contain abundant ω-PUFAs lead to the properties of cleansing, non-clogging, moisturizing, and semi-drying. The above mentioned properties of watermelon seeds make it suitable for preparing skin-care products (soaps, facial oils, eye creams, lotions, and hair-care)
preparations. Further, the ω-PUFAs have led to watermelon seed oil’s popularity in treating complications of carcinogenic and cardiovascular (Logaraj, 2011).

CONCLUSION AND OUTLOOK

Good cultivation techniques and practices are required to produce good quality watermelon and high production yield. This includes several aspects, such as variety of watermelon, soil selection, planting techniques, irrigation, weeding, pollination, pruning, harvesting, and post-harvest handling. In addition, watermelons are susceptible to various insect pest infestations, such as aphids, thrips, armyworm, fruit fly, ant, and grasshopper, as well as diseases, such as downy mildew, powdery mildew, anthracnose, gummy stem blight, alternaria leaf spot, cercospora leaf spot, myrothecium leaf spots, bacterial fruit blotch, leaf mosaic, tobacco ring spot virus, leaf rot, stem rot, fusarium wilt, bacteria wilt, damping-off, scab, and blossom end rot, which can attack all parts of the plants. Hence, proper pest and disease controls are of utmost important to prevent adverse effects on crop growth and production.

Watermelon is highly nutritious. The flesh is normally consumed as a popular dessert or converted into tasty and refreshing beverage, i.e., watermelon juice. Recent studies have found that watermelon (flesh, rind, and seed) appeared to possess health promoting properties due to the presence of phytochemicals, such as carotenoids, citrulline, and polyphenols. Investigations on the edible portion of watermelon and its residues, such as rind and seed, showed that these parts of the watermelon have the potential in functional food (natural food additive), cosmetic, and pharmaceutical applications. Despite its high nutritional content and health benefits, products derived from watermelon are very scarce in the market. More novel products are to be expected once the industries realized the potential and benefits of this fruit.

Conflicts of Interest

The authors declare there is no conflict of interest in this review.
ACKNOWLEDGMENT

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Chapter 3

THE PRODUCTION OF BEANS VIGNA UNGUICULATA (L.) WALP FERTIGATED WITH YELLOW WATER ASSOCIATED WITH CASSAVA WASTEWATER

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ABSTRACT

This research aimed to evaluate the production of beans cowpea fertigated with Human urine associated with Cassava Wastewater as an alternative source of nutrients. The experiment was conducted in a greenhouse located in the Campus I of the Federal University of Campina Grande. The treatments consists in fertigation with mineral fertilizers, organic fertilizers compound of humane urine and Cassava Wastewater and organomineral composed of Human urine, Cassava Wastewater and minerals consisting of NPK. It was concluded that the seven variables analyzed only two showed a significant difference between the means; the fertigation with only Cassava Wastewater promoted the maximum average number of pods per plant, dry weight of 100 grains, dry mass of roots and harvest index and the use of Human urine or Cassava Wastewater can replace mineral fertilizer consists of NPK in culture cowpea.

Keywords: agricultural use of waste, eco sanitation, recycling of nutrients

INTRODUCTION

The recycling of nutrients contained in wastewater is a sustainable technique, because it minimizes the use of mineral fertilizers and the environmental impacts resulting from the lack of environmental management of the waters.
According to Sousa et al., (2008), in the last sixteen years several studies based on the separation of urine and feces were developed. Separation of urine may provide a “free” hygienic fertilizer which can be used in agriculture (KVARNSTRÖM et al., 2006). According to Karak and Bhattacharyya (2011) urine is an invaluable source of nutrients that has been used in agriculture since ancient times.

Another effluent that presents great potential for the recycling of nutrients through agricultural reuse is the Cassava Wastewater, because according to Conceição et al., (2013), is rich in nitrogen, phosphorus, potassium, calcium, magnesium, copper, zinc and manganese and can be used as a potential fertilizer.

As far as researches with agricultural use of Human urine and Cassava Wastewater, Araújo et al., (2015), studied the components of hydroponic green forage (HGF) of corn (Zea mays L.) fertilized with Human urine as an alternative source of nutrients; Santos Júnior et al., (2015), evaluated the parameters of grain production and millet phytomass irrigated with Human urine associated with domestic sewage; Araújo et al., (2012 and 2015) evaluated the growth and yield of maize fertilized via leaf with Cassava Wastewater syrup and Saraiva et al., (2007) that investigated the use of Cassava Wastewater applied in the soil fertirrigation. These researchers concluded that the agricultural use of Human urine and Cassava Wastewater had a positive effect on the analyzed variables.

In this context, the present study aimed to evaluate the production of fertile bean vignes with Human urine associated to the Cassava Wastewater as an alternative source of nutrients.

**MATERIALS AND METHODS**

This research was carried out between November 10, 2015 and March 10, 2016. The experiment was conducted in a greenhouse located at Campus I of the Federal University of Campina Grande (UFCG), city of Campina Grande (7°13’50” S, 35°52’52” W, 551m altitude), state of Paraíba.

In the research environment, experimental units composed by pot-plants were set up. The vessels used were of plastic with 15,0 L of capacity installed in spacing of 0,80 m between row and 0,50 m inside the row, placed under base of bricks.

Each vessel was drilled in the base for introduction of a drain, that is, a hose 15 cm long and 6 mm nominal diameter, which was coupled to a PET
bottle with 2.0 L of capacity to collect the drainage effluent, aiming to allow its recirculation. In the filling, the vessels received a layer of 0.50 kg of gravel (number zero) which covered the base and another of 15.0 kg of sandy-loam soil, duly discharged and sieved, from the rural area of the municipality of Esperança, PB, whose analyzed characteristics revealed the following values: pH (H₂O) = 5.58; CE = 0.56 mmhos cm⁻¹; Al = 0.00 cmolc dm⁻³; Mg = 2.78 cmolc dm⁻³; Ca = 9.07 cmolc dm⁻³; K = 0.33 cmolc dm⁻³; Na = 1.64 cmolc dm⁻³; P = 3.98 mg dm⁻³; S = 13.72 cmolc dm⁻³; CO = 1.70%; MO = 2.93% e d = 1.28 g cm⁻³.

After filling the pots with the substrate, irrigation is started until the field capacity is reached, posteriorly, the pits were then opened and the seeds were seeded by depositing five seeds per pot, of the cowpea beans culture, marataó cultivar and with 7 days after sowing (DAS) the thinning was done leaving two plants per pot.

Irrigation water volumes were estimated individually for each experimental plot with a 2-day irrigation shift, based on the water balance (difference between the average applied volume sufficient to maintain the soil at the field capacity was increased by a fraction of leaching of 0.20, according equation 1: \( V_i = (V_a - V_d)/1-F_L \) (1); where \( V_i \), \( V_a \), \( V_d \) and \( F_L \) are the volume of water to be applied to the irrigation, the volume of water applied, drained volume in the previous irrigation and fraction of leaching, respectively. The water used in the irrigation was collected in the water supply network of Campina Grande.

The experimental design was completely randomized, with five replications and five treatments, totaling 25 experimental plots. Treatments consisted of NPK fertigation’s (Treatment 1 - NPK); Human urine only (Treatment 2 - U); Only Cassava Wastewater (Treatment 3 - M); Human urine plus Cassava Wastewater (Treatment 4 - U + M) and Human urine plus Cassava Wastewater plus P (Treatment 5 - U + M). Mineral fertilizers were composed of urea (45.9% N), simple superphosphate (18.9% of P₂O₅) and potassium chloride (60% K₂O).

Fertigations were started at 10 days after sowing (DAS). In each plot were applied the equivalent of 100 mgN kg⁻¹ of soil, 300 mgP kg⁻¹ of soil and 150 mgK kg⁻¹ of soil, as recommended by Novais et al., (1991).

The amounts of Human urine and Cassava Wastewater applied in each plot were estimated based on the nitrogen and potassium concentrations present in the effluents and the dose recommended by Novais et al., (1991) (100 mgN kg⁻¹ soil and 150 mgK kg⁻¹ soil).
The Production of Beans *Vigna unguiculata* (L.)…

Table 1. Physicochemical characterization of Human urine and Cassava Wastewater used in the experiment

<table>
<thead>
<tr>
<th>Effluent</th>
<th>Parameters</th>
<th>TKN</th>
<th>N-NH&lt;sub&gt;3&lt;/sub&gt;</th>
<th>NO&lt;sub&gt;3&lt;/sub&gt;</th>
<th>P-PO&lt;sub&gt;4&lt;/sub&gt;-3</th>
<th>K</th>
<th>Na</th>
<th>Ca + Mg</th>
<th>pH</th>
<th>CE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urine</td>
<td>g L&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>6.668</td>
<td>5.257</td>
<td>0.002</td>
<td>0.325</td>
<td>1.558</td>
<td>2.509</td>
<td>0.034</td>
<td>9.12</td>
<td>42.7</td>
</tr>
<tr>
<td>Cassava Wastewater</td>
<td>1.199</td>
<td>0.336</td>
<td>0.019</td>
<td>0.338</td>
<td>4.004</td>
<td>0.096</td>
<td>2.800</td>
<td>3.75</td>
<td>11.75</td>
<td></td>
</tr>
</tbody>
</table>


For treatments containing mineral fertilizers (treatments 1 and 5) the fertigation’s were divided in 3 times and applied to 10, 20 and 30 DAS. For treatments containing Human urine (treatments 2), Cassava Wastewater (treatments 3) and Human urine plus Cassava Wastewater (treatments 4 and 5), fertigation’s were divided in 10 times and applied to 10, 12, 14, 16, 18, 20, 22, 24, 26, 28 and 30 DAS.

Human urine was stored in a 20.0 L plastic bucket and kept hermetically sealed for 60 days prior to use. The Cassava Wastewater was also stored for 60 days in a plastic container with a capacity of 85 liters, but leaving an empty space of 5 cm inside and closed. In the bucket lid was installed a hose with the other end dipped in a container with water at the height of 5 cm, for the exit of the gases generated during the biodigestion of the effluent.

After the storage period, the urine and the Cassava Wastewater were analyzed, according to the methodology recommended in Standard Methods for Wastewater (APHA, 2005), whose parameters are presented in Table 1.

At the end of the harvest (120 DAS) the following variables were evaluated: number of pods per plant (NPP), counting all pods produced by the plant during the productive cycle; Length of pod (LP), performed by measuring all pods produced by the plant; Number of grains per pod (NGP), performed by counting the grains produced in each pod per plant; Mass of 100 grains (M100g), estimated by weighing three replicates of 100 grains, obtained after thawing the dried pods in a temperature controlled oven at 65 °C for 72 hours.

At the end of the harvest the plants were collected to determine the dry mass of the aerial part (DMAP) - performed by cutting the plant close to the soil, drying (in a greenhouse with controlled temperature at 65 °C for 72 hours) and weighing (digital scale Accuracy) of the phytomass produced during the entire crop cycle. In possession of the dry mass of the aerial part.
and the dry mass of the grains produced in each plot were determined the
harvest index by the dry matter ratio of seeds divided by total dry matter
multiplying by 100.

After the collection of the aerial part, the root system was also collected,
for later determination of the dry mass of the roots (DMR).

The results of the studied variables were submitted, through the software
ASSISTAT v. 7.7 Beta, the analysis of variance with the means compared by
the Tukey test at the 5% probability level.

RESULTS AND DISCUSSION

The results of the mean number of pods per plant (NPP), number of grains
per pod (NGP), pod length (LP), weight of 100 grains (M100g), shoot dry
mass (DMAP) and roots (DMR), and harvest index (HI) are presented in
Table 2.

According to Table 2, the analysis of variance of the analyzed variables
indicated that there was a significant statistical difference (p < 0.01 and p
<0.05) among treatments, only for the variables dry mass of the shoot (DMAP)
and harvest index (HI).

Mean of the variables, number of pods per plant (NPP), pod length (LP),
number of grains per pod (NGP), dry matter of 100 grains (M100g) and roots
(DMR) did not present statistical differences among themselves.

The maximum numbers of pods per plant and grains per pods (NPP and
NGP) were 26.25 and 14.49, obtained when fertigation’s were carried out with
only Cassava Wastewater (treatment 3) and Human urine (treatment 2),
respectively.

The maximum average length of pods per plant (LP) was 17.35 cm,
obtained through NPK fertigation’s (treatment 1). According to Davari et al.,
(2012), increased pod formation using organic fertilizer and crop residues can
be attributed to the improved plant development due to the efficient use of the
nutrients available in the soil by the plant.

Results of NPP, NGN and LP, similar to those of the present research,
were obtained by Santos et al., (2007) when evaluating the response of the
fertigated cowpea with biofertilizer.

The average maximum of the dry mass of 100 grains was 21.06 g obtained
with the only Cassava Wastewater fertigation’s. Studying the productive
performance of common bean cultivated with bovine manure, biofertilizer,
inoculant, mineral fertilization and different combinations of these, Martins et
al., (2015), also did not obtain significant statistical difference between averages of dry mass of 100 grains.

There was a statistical difference between them, the mean dry mass of the aerial part of the treatments 1 (fertigation’s with NPK) and 7 (fertigation’s with urine plus Cassava Wastewater associated with mineral fertilization). Fertigation’s with urine plus Cassava Wastewater associated with mineral fertilization resulted in the average maximum (114.72 g) dry mass of the aerial part of the bean.

Evaluating the use of bovine biofertilizer and sanitary sewage treated in fertigation in cowpea beans fertigation, Sousa et al., (2013) and Rebouças et al., (2010), obtained a positive response with dry mass of aerial parts gains. Feitosa et al., (2015) studying the growth of fertigated cowpea beans plants with different concentrations of domestic effluent and salt water, obtained the maximum dry mass of shoot under fertigation with 100% domestic sewage.

The average maximum dry mass of the roots was 8.4 g plant⁻¹, obtained through fertigation’s with only Cassava Wastewater. Fertigation’s with Cassava Wastewater provided a gain of the dry mass of the bean roots. Evaluating the effects of inoculation with Bradyrhizobium elkanii and fertilization with P, K and Mo on cowpea beans Gualter et al., (2008) when applying only PK and Mo obtained an average of 8.87 g dry mass of root per plant.

### Table 2. Means of the number of pods per plant (NPP), length pods (LP), number of grains per pod (NGP), dry mass of 100 grains (M100g), dry mass of aerial part (DMAP) e dry mass of roots (DMR) and harvest index (HI) of the cowpea beans fertigated with Human urine, Cassava Wastewater e NPK

<table>
<thead>
<tr>
<th>Treatments</th>
<th>NPP Pods plant⁻¹</th>
<th>NGP Grains vagens⁻¹</th>
<th>LP cm</th>
<th>M100g g planta⁻¹</th>
<th>DMAP</th>
<th>DMR</th>
<th>HI %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (NPK)</td>
<td>19.75a</td>
<td>12.32a</td>
<td>17.35a</td>
<td>20.27a</td>
<td>86.59b</td>
<td>7.06a</td>
<td>40.77ab</td>
</tr>
<tr>
<td>2 (U)</td>
<td>22.25a</td>
<td>14.49a</td>
<td>17.33a</td>
<td>20.17a</td>
<td>91.94ab</td>
<td>4.20a</td>
<td>48.18ab</td>
</tr>
<tr>
<td>3 (M)</td>
<td>26.25a</td>
<td>12.29a</td>
<td>16.90a</td>
<td>21.06a</td>
<td>94.51ab</td>
<td>8.40a</td>
<td>54.11a</td>
</tr>
<tr>
<td>4 (U + M)</td>
<td>25.00a</td>
<td>11.22a</td>
<td>15.90a</td>
<td>19.04a</td>
<td>94.09ab</td>
<td>7.40a</td>
<td>45.85ab</td>
</tr>
<tr>
<td>5 (U + M + P)</td>
<td>21.00a</td>
<td>11.38a</td>
<td>16.08a</td>
<td>19.60a</td>
<td>114.72a</td>
<td>4.90a</td>
<td>35.16b</td>
</tr>
<tr>
<td>F</td>
<td>1.59ms</td>
<td>1.28ms</td>
<td>1.84ms</td>
<td>1.14ms</td>
<td>3.49*</td>
<td>1.25ms</td>
<td>5.083**</td>
</tr>
</tbody>
</table>

Means followed by equal letters in the column do not differ from each other by the Tukey test at 5% probability. ms, **, * Not significant, significant at 1 and 5% probability by F test.
The harvest index showed a statistically significant difference between the two mean values for the fertigation’s with Cassava Wastewater and Human urine with Cassava Wastewater associated with mineral fertilization (treatment 7). The highest average was 54.11% obtained through fertigation’s with Cassava Wastewater. The lowest mean of the harvest index was 35.16% obtained through fertigation’s with treatment 7. The other averages did not differ statistically between them.

According to the data presented in Table 2, it is observed that although there isn’t significant statistical difference between the means of the variables, number of pods per plant, pod length, number of grains per pod, dry mass of 100 grains and mass dry matter of the roots, when fertigated with the wastewater presented values superior to the plants that were fertigated with chemical fertilizer formulated by NPK.

**CONCLUSION**

1. Of the seven variables analyzed, only two presented a significant difference between the means;
2. Fertilizations with only Cassava Wastewater promoted the maximum average number of pods per plant, dry matter of 100 grains, dry mass of the roots and harvest index;
3. Human urine and Cassava Wastewater are alternative sources of nutrients that can be used in the fertigation of cowpea;
4. The use of Human urine or Cassava Wastewater can replace mineral fertilization composed by NPK in the cowpea culture.

**REFERENCES**


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Chapter 4

THE POSSIBILITY OF UTILIZATION OF LOAC TECHNIQUE FOR DETECTION OF GLUTEN PROTEINS: CONNECTION WITH THE TECHNOLOGICAL QUALITY OF WHEAT

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ABSTRACT

Estimation of technological quality of wheat is always connected with possibility that the mixture of wheat flour and water form dough with unique rheological properties, which is not the case with other cereal flours. Numerous surveys have shown that gluten proteins (gliadins and glutenins), originating from endosperm of wheat kernel, are the key factor for viscoelastic properties of dough and end-use quality of wheat flour. Since a unique system for identification of all gluten proteins does not exist, various techniques are used for their accurate and precise determination. In the last decade, special attention has been given to the development of the microfluidic or Lab-on-a-Chip (LoaC) devices which are used for sensitive chemical and biological analyses. Also, it is worth to note that LoaC devices have found application for determination of gluten proteins. Therefore, this chapter will be focussed on the

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possibility of LoaC platforms application for identification and quantification of wheat gluten proteins as well as their connection with technological quality of wheat. Additionally, the current chapter is intended to highlight the great potential of LoaC technique for fast, accurate and high-throughput identification and quantification of wheat gluten proteins.

**Keywords:** gluten proteins, wheat, glutenins, gliadins, technological quality

**INTRODUCTION**

Technological quality of wheat is associated with the possibility of using its flour mixed with water in order to obtain dough with unique rheological properties. This is not the case with other cereal flours. During the manufacturing process flour and water are mixed. Flour takes on moisture and mechanical energy is introduced. This results in transforming the gluten protein into a continuous cohesive viscoelastic gluten network (Singh and MacRitchie, 2001).

The result of this process is the formation of dough. Its characteristics and behavior in the processing are defined by the indirect, i.e., rheological parameters for monitoring the development of the gluten network during kneading the dough, which was explained in the studies by Walker and Hazelton (1996) and Cato and Mills (2008). Another monitored property is dough strength, i.e., measuring its resistance and extensibility (Zhang et al., 2007). Some research focused on determining the existence of a correlation with indirect indicators of quality, such as protein content (Aitken and Geddes, 1934) and improving the quality of wheat with low protein content (Aitken and Geddes, 1939), because the volume of wheat bread can be reliably predicted on the basis of protein content in wheat grain (Dowell et al., 2008).

Technological quality of wheat is affected by different factors. Viscoelastic properties of dough and baking qualities of flour are mostly influenced by gluten proteins, gliadins and glutenins (Panozzo et al., 2001). Numerous studies have been conducted aiming to investigate the effect of glutenin (Branlard and Dardevet, 1985; Blumenthal et al., 1995; Gupta et al., 1991; Huebner et al., 1999; Lawrence et al., 1988; Luo et al., 2001; MacRitchie et al., 1991; Ng and Bushuk, 1988; Payne et al., 1984; Pirozi et al., 2008; Wrigley and Beitz, 1988) and gliadin (Gil–Humanes et al., 2012; Huebner et al., 1999; Metakovsky et al., 1990; Payne et al., 1984; Van
Lonkhuijsen et al., 1992). They showed that genotypic variations can significantly affect the viscoelastic properties of dough and technological quality of wheat.

Gluten proteins make up 85% of proteins in endosperm of wheat kernel (Carceller and Aussenac, 1999). They are found in the endosperm of ripe wheat where they form a continuous matrix around the starch granules. They consist of two distinct types of proteins: the monomeric gliadins and the polymeric glutenins. These complex compounds are the key factor for the viscoelastic properties of dough and baking quality of wheat. (Panozzo et al., 2001). In the reaction of a larger share of gliadin and glutenin and a smaller share of starch and other compounds with water, wet gluten is formed. Its quantity is a characteristic of wheat genotypes. (Varga et al., 2003). Wet gluten content positively correlates with grain protein content (Varga et al., 2003), while the qualitative features of gluten are expressed with gluten index. The values of this parameter that are necessary for the production of bread, range between 75% and 90% among Croatian wheat varieties (Ćurić et al., 2001).

**GLUTEN PROTEINS**

**Gliadins**

As previously mentioned, gliadins are monomeric proteins with molecular weight of 30 000 to 75 000 Da. Gliadins are known to have extensive genetic polymorphism, hence are used to identify wheat varieties (Wrigley et al, 1982). On the basis of their electrophoretic mobility in an acidic environment in the A-PAGE (Acid Polyacril Amid Electrophoresis), gliadins are classified into: α-gliadins, β-gliadins, γ-gliadins and ω-gliadins. By applying scattered x-radiation at low angles, Thomson et al., (1999) determined that the Capitole cultivar of wheat had molecular weight of α-gliadin at 35 000, γ-gliadin at 45 000, while the molecular weight of ω-gliadin was 58 000 Da. The genes which encode these proteins are located on the short parts of chromosomes 1 and 6 (Figure 1). They are closely related to genes present in three homologues of chromosome 1 loci: Gli A1, Gli B1 and Gli D1. Chromosome 6 has loci Gli A2, Gli B2 and Gli D2 (Brown and Flavell, 1981). Gli 1 genes encode ω-gliadins and γ-gliadins, while Gli 2 genes encode α-gliadins and β-gliadins. Gliadins on Gli 1 locus are closely connected to the low molecular weight glutenins, LMW (Low Molecular Weight) of Glu 3 locus, which are present on...
chromosome 1 (Figure 2) (Metakovsky, 1991; Metakovsky et al., 1984). α-gliadins and β-gliadins mostly accumulate in the early stages of wheat grain development (Zhu and Khan, 1999). Gliadin subunits have a high content of glutamine amino acid. For example, the ω-gliadins contain more than 50% of the glutamine (Lasztity, 1995). The content of proline in gliadins is high and if compared with HMW (high molecular weight) glutenins, it is much higher. The high content of proline has an important role in the secondary structure of gliadin.

It is known that gliadins are low in amino acids with the base R residues of lysine, arginine and histidine (Kasarda et al., 1974). Most α-gliadins and β-gliadins, as well as some γ-gliadins have similar amino acid sequence of the N-terminus of the protein. α-gliadins, β-gliadins and γ-gliadins have 6 or 8 cysteine residues, which results in the creation of 3 or 4 intramolecular disulphide bonds (Kasarda et al., 1984). Even though HMW and LMW glutenins form disulphide bonds by cross-linking in the gluten matrix, a small portion (5 to 10%) of α-gliadins and γ-gliadins participate in cross-linking within the gluten matrix, while ω-gliadins may also play a role in increasing the polymer (Kukataite et al., 2004).

<table>
<thead>
<tr>
<th>Long parts</th>
<th>Short parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gli 1/Gli 3</td>
<td></td>
</tr>
<tr>
<td>1 A---------I---------O---------I---</td>
<td></td>
</tr>
<tr>
<td>1 B---------I---------O---------I---</td>
<td></td>
</tr>
<tr>
<td>1 D---------I---------O---------I---</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Gli 2</td>
<td></td>
</tr>
<tr>
<td>O---------I---------6 A</td>
<td></td>
</tr>
<tr>
<td>O---------I---------6 B</td>
<td></td>
</tr>
<tr>
<td>O---------I---------6 D</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Position of gliadin loci on short parts of chromosomes 1 and 6. “I” marks the position of Gli 1/Gli 3 locus and Gli 2 locus. “O” marks the position of the centromere.
Glutenins

Glutenins are among the largest proteins found in nature. They are polymeric proteins linked by disulphide bonds having molecular weight greater than 20 million Da (Wrigley 1996). On the basis of electrophoretic mobility, they are divided into glutenin subunits, GS (Glutenin Subunits) of high molecular weight (HMW–GS) and glutenin subunits of low molecular weight (LMW–GS). Sizes HMW–GS, determined by SDS–PAGE technique (Sodium Dodecyl Sulphate – Polyacrylamide Gel Electrophoresis) are in the range 80-130 kDa (Bunce et al., 1985), and their specific composition is one of the most important genetic factors used to determine rheological properties of dough wheat cultivars (Payne et al., 1987a). LMW–GS sizes determined by SDS–PAGE are in the range of 30 to 50 kDa (Gras et al., 2001). The genetic loci that control the synthesis of protein gluten in wheat can be found in the first chromosome. As shown in Figure 2, the HMW glutenins are encoded by the Glu 1 locus of the long part of chromosome (Payne and Lawerence, 1983). Three genetically unrelated loci (Glu A1, Glu B1 and Glu D1) are located on homologous chromosomes 1A, 1B, 1D and control the synthesis of HMW glutenin (Figure 2) (Gálová et al., 2002; MacRitchie and Lafiandra; 2001). Synthesis of LMW glutenin is controlled by three unrelated loci as well (Glu A3, Glu B3 and Glu D3) located on the short parts of chromosomes 1A, 1B and 1D.

The amino acid composition of proteins makes up the primary structure of proteins. Although the amino acid residue does not take part in the formation of peptide bridges, it influences the interaction of the protein with other proteins and other compounds. Glutenins and gliadins have a similar amino acid composition.

<table>
<thead>
<tr>
<th>Long parts</th>
<th>Short parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glu 1 (HMW)</td>
<td>Glu 3 (LMW)</td>
</tr>
<tr>
<td>1A</td>
<td>I</td>
</tr>
</tbody>
</table>

Figure 2. The wheat chromosome of 1A, 1B and 1D gene locations of Glu 1 (HMW) and Glu-3 (LMW) glutenins on the long and short part of chromosome.

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Protein chain is often formed in the form of helix, and makes the secondary structure of the protein. Proline inhibits the formation of these types of structures in wheat. Amino acid cysteine has an important role in the secondary structure of glutenin protein. Cysteine has a unique feature – it links the protein chains by disulfide bonds (Gras et al., 2001). The prevailing opinion is that the structure of the HMW glutenin is a mixture of polypeptide units, which are cross-linked via intermolecular disulfide bonds and thus produce large molecular weight ranges, which can be measured in million Da.

LMW glutenin structure consists of cysteine residues that help the formation of glutenin polymers. Based on the number of cysteine residues in the LMW glutenins, there are two types of LMW subunits which participate in the formation of the polymer. LMW subunits with two or more cysteine residues, involved in the formation of intermolecular disulfide bonds among the HMW glutenins, enable the reaction of glutenin polymer propagation. Conversely, LMW subunits with one cysteine residue participate in the termination reaction of glutenin polymers, and in that way stop its further increase (Masci et al., 1998).

Polymerization of glutenin subunits begins 10 days after wheat flowering, or earlier, and significantly increases during the grain filling stage, until its full maturity. Content of HMW glutenin subunits in this process significantly increases, whereas LMW decreases (Zhu and Khan, 1999).

HMW glutenin subunits are classified into two types, x and y (Shwery et al., 1992). X-type subunit has a lower electrophoretic mobility in SDS–PAGE and a higher molecular weight than y-type subunits. Glu A1 locus encodes only subunits of x-type, Glu B1 locus encodes both x-type and y-type or x-type only, while Glu D1 encodes both x-type and y-type subunits. The separation of HMW glutenin subunits on SDS-PAGE indicated the presence of several alleles on each locus (Payne and Lawerence, 1983).

Table 1. The Glu score system according to Payne for common Glu-1 allele

<table>
<thead>
<tr>
<th>Glu–A1</th>
<th>Glu–B1</th>
<th>Glu–D1</th>
</tr>
</thead>
<tbody>
<tr>
<td>score</td>
<td>Allele</td>
<td>subunit</td>
</tr>
<tr>
<td>3</td>
<td>a</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>b</td>
<td>2*</td>
</tr>
<tr>
<td>1</td>
<td>c</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

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In each of wheat varieties there can be from 3 to 5 different HMW glutenin subunits. Number of formed subunits is small due to the disappearance of certain genes during evolution (Lafiandra et al., 2000).

Payne and Lawrence (1983) developed a numerical identification system for HMW glutenin subunits on the basis of their electrophoretic mobility. This system is still used today, as different techniques for the same GS receive different levels of molecular weights. Originally, the small numbers (for example 1 and 2) marked subunits with lower mobility on SDS–PAGE. Over time it has become difficult to follow this logical order, as the existence of the new subunits was established subsequently. Payne and Lawrence (1987) developed a point system according to Payne – Glu score (Table 1), in order to explain how the genetic factor – specific composition of HMW glutenin subunits affects the properties of dough wheat varieties. The individual number of points of each subunit/subunit pair, are added up to calculate the total Glu score, and its maximum value for wheat is 10. This system can only explain insufficiently significant percentage of variation of the value of bread volume (Hamer et al., 1992). The protein chain of HMW glutenin subunits is composed of three different parts (Shewry et al., 1989): the central part which consists of repetitive amino acid sequence (Harberd et al., 1986) and the side parts ending with N and C termini, consisting of non repetitive amino acid sequences (Halford et al., 1987). The amino acid sequences of HMW glutenin subunits, have 4 to 7 cysteine residues located at the N-terminus and C-terminus (Shewry et al., 1992). The subunit 1Dx5 has extra cysteine residue at the N-terminus which does not have 1Dx2 subunit (Gras et al., 2001).

Based on the analysis of extracts of wheat gluten polymer fractions SDS–PAGE, LMW glutenin subunits are classified into the B–type, C–type and D–type. After the molecular analysis, it was found that C-type and D-type LMW glutenin subunits are gliadins with cysteine residues (α, β, γ and ω), which are incorporated into the polymer fraction, while the B-type subunits are real LMW glutenin subunits (D’Ovidio and Masci, 2004). It is estimated that every variety of wheat contains between 7 and 16 different LMW–GS (Gupta and Shepherd, 1990).
THE EFFECT OF GLUTEN PROTEINS ON THE TECHNOLOGICAL QUALITY OF WHEAT

Numerous studies have been carried out to investigate the influence of gluten protein glutenins on the viscoelastic properties of dough and the technological quality of wheat (Branlard Dardevet and 1985, Blumenthal et al., 1995; Gupta et al., 1991; Huebner et al., 1999; Lawrence and al., 1988; Luo et al., 2001; MacRitchie et al., 1991; Ng and Bushuk, 1988; Payne et al., 1984; Piroozi et al., 2008; Wrigley and Beitz, 1988) and gliadin (Gil Humanes et al., 2012; Metakovsky et al., 1990; Payne et al., 1984; Van Lonkhuijsen et al., 1992). The results of these studies showed that genotypic variations significantly influence the viscoelastic properties of dough and the technological quality of wheat.

The Influence of Glutenins

Payne et al., (1984) conducted one of the first studies about the impact of gluten on the technological quality of wheat, and proved that glutenin is responsible for dough elasticity. The opinion which prevails in the scientific world is that the differences in glutenin properties are much more important than the influence of gliadin and that they can provide a better explanation for the differences in technological and baking properties of wheat. There have been more than 20 different HMW–GS and more than 40 different LMW–GS identified in the different varieties of wheat (Gupta and Shepherd, 1990), which explains a considerable diversity in the glutenin composition of the investigated wheat cultivars as well as significant variations in the wheat technological quality. Ng and Bushuk (1988) think that the composition of HMW–GS glutenin can explain the variation of 67% of wheat flour baking properties, the impact of their quantity, their relative share, as well as the distribution of molecular weight on the technological quality of wheat. In addition to the influence of glutenin composition of HMW–GS, glutenin composition of LMW–GS also affects the technological quality of wheat, given that these subunits impact resistance and extensibility of dough (Gupta et al., 1991). The combined effect of HMW–GS and LMW–GS on the technological quality of wheat is given at the end of this chapter.
The Influence of HMW–GS

Lawrence et al., (1988) proved that the greatest contribution to the technological quality of wheat is provided by Glu–D1, followed by Glu–B1 and finally Glu–A1 locus. In addition, it was found that certain HMW glutenin subunits are important for the technological quality of wheat. They were encoded at Glu A1 (1, 2*), Glu B1 (17 + 18) and Glu D1 (5 + 10, 2 + 12) loci (Payne et al., 1987b). The technological quality of wheat depends on dough elasticity and dough extensibility, which is significantly affected by the presence or absence of certain HMW glutenin subunits (Payne et al., 1987b).

From the moment when Payne et al., (1981; 1984) established the existence of a correlation between HMW glutenin subunit composition and technological quality, research has mainly been focused on determining the presence or absence of certain subunits. For example, it is a known fact that a pair of HMW–GS from D locus 5+10 forms stronger dough than a pair of HMW–GS subunits from D locus 2 + 12, because of one cysteine residue more in a repetitive amino acid sequence 5 subunit (Lafiandra et al., 1993). This is consistent with the assumption by Bietz (1987) who pointed out that the number and position of cysteine residue enables intermolecular connection and which is partially responsible for the qualitative differences present between certain HMW glutenin subunits. Also, Huebner et al., (1999) reported that there are significant differences in the values of certain indicators that were obtained by mixograph (water absorption, kneading time and mixograph number), between groups of soft winter wheat varieties with HMW–GS 5 + 10 and 2 + 12. Also, the varieties that have HMW–GS 5 + 10 at D locus can produce more quality biscuits. On the other hand, Johansson et al., (1994), and Blumenthal et al., (1995) showed that some wheat varieties with HMW–GS 5 + 10 have inferior technological quality than cultivars with HMW–GS 2 + 12. Subunits 1 and 2* at Glu A1 locus are characterized by positive correlation with alveograph indicators W and G (alveograph volume of air for forming dough bubble), while a pair of subunits 17 + 18 at Glu B1 locus affect of the dough extensibility (Branlard and Dardevet, 1985). It is believed that the subunit 1 at Glu A1 locus has a positive effect because of its unique structure which allows bigger and more stable protein aggregates. The low value of technological quality parameters in some wheat varieties is associated with the lack of glutenin subunit at Glu A1 locus, with a present pair of HMW–GS 4 + 8 with Glu B1 locus and a pair of HMW–GS 2 + 12 Glu D1 (Weegels et al., 1996). For close wheat genotypes differing in HMW–GS at Glu B1 locus, it has been proved that the presence of 7 + 8 or 7 + 9 subunits instead of 20x +
20y or 26 + 27 is associated with a higher content of insoluble polymeric proteins, greater dough strength and better baking qualities (Piroozi et al., 2008). This can be explained by the fact that subunit 7 has more cysteine residues which increase HMW glutenin polymer. The examination of close isogenic lines, where certain glutenin subunits were removed, confirmed that the force used for dough kneading and technological quality of wheat, or baking properties, were reduced because of their removal (MacRitchie and Lafiandra, 2001). When the cultivar Soisson had subunit 2* at Glu A1 locus replaced with subunit 1 via transgenesis, Field and colleagues (2008) found that this change increased dough strength.

In order to predict wheat quality it is not sufficient merely to determine the presence and/or absence of certain HMW–GS subunits, but it is necessary to determine the absolute amounts and the relative shares of HMW–GS (MacRitchie et al., 1991). In accordance with this, Wieser et al., (1994) found a statistically significant correlation between the amount of HMW–GS and maximum resistance of dough and gluten. By adding HMW–GS to flour, Veraverbeke et al., (1998) showed that, although it increases mixographically measured dough strength, it does not affect the improvement of baking characteristics, i.e., there is no increase in bread volume. It is possible to examine the influence of individual HMW–GS if they are produced bacteriologically. Bekes and Anderson (2011) showed that the addition of individual subunits HMW–GS x-type (2 and 5) from Glu D1 locus in five different dough specimens has a greater impact on the dough parameters than it is the case with HMW–GS–y type (10 and 12). In this study, it was found that in the case of joint addition of x and y subunits (5 + 10 and 2 + 12, each pair of subunits separately), their combined effect is greater than the effect of individual subunits.

The results obtained by Anderson and Bekes (2011) show that x-type subunits have a greater effect on dough parameters than y-type subunits, which is in line with the results of research by Wrigley Beitz (1988). Also, Wrigley and Beitz (1988) reported that molecular weight distribution of glutenin polymer plays an important role in determining the viscoelastic properties of dough. This fact is explained by the theory of the polymer, i.e., that only polymers having a molecular weight above certain size contribute to the elasticity of glutenin polymer (MacRitchie, 1992). This is consistent with several studies which explained the existence of a positive correlation between dough strength/baking properties and sizes of the largest glutenin polymers (Singh and MacRitchie, 2001; Veraverbeke and Delcour, 2002).
Table 2. A systematized influence of individual HMW–GS, or pairs from the same locus on the technological quality of wheat

<table>
<thead>
<tr>
<th>Subunits from Glu–A1 loci</th>
<th>Dough strength</th>
<th>Dough properties during mixing</th>
<th>Dough extensibility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dough strength</td>
<td>Dough properties during mixing</td>
<td>Dough extensibility</td>
</tr>
<tr>
<td>1</td>
<td>positive correlation (Branlard and Dardevet, 1985; Field et al., 2008)</td>
<td>–</td>
<td>positive correlation (Branlard and Dardevet, 1985)</td>
</tr>
<tr>
<td>2*</td>
<td>positive correlation (Branlard and Dardevet, 1985)</td>
<td>–</td>
<td>positive correlation (Branlard and Dardevet, 1985)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Subunits from Glu–B1 loci</th>
<th>Dough strength</th>
<th>Dough properties during mixing</th>
<th>Dough extensibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>17+18</td>
<td>–</td>
<td>–</td>
<td>Possess influence (Branlard and Dardevet, 1985)</td>
</tr>
<tr>
<td>Subunits from Glu–D1 loci</td>
<td>Dough strength</td>
<td>Dough properties during mixing</td>
<td>Dough extensibility</td>
</tr>
<tr>
<td>5+10</td>
<td>Stronger dough (Lafiandra et al., 1993)</td>
<td>Exist difference between these two pairs of HMW–GS (Huebner et al., 1999)</td>
<td>–</td>
</tr>
<tr>
<td>2+12</td>
<td>Weaker dough (Lafiandra et al., 1993)</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

**The Influence of LMW–GS**

The influence of LMW–GS has not been studied in the same depth as the influence of the composition of HMW–GS and it is difficult to determine their separate effect on technological quality of wheat without testing HMW–GS. In the study, Luo et al., (2001) concluded that the specific composition of LMW–GS has a greater impact on dough extensibility than on dough strength and these qualities are directly associated with HMW–GS. Similar results were reached by Metakovsky et al., (1990), who confirmed the existence of a significant correlation between the presence of LMW–GS and resistance and dough extensibility. Up to 46% of variation of the extensographic resistance and dough extensibility values is explained with LMW–GS (Gupta et al., 1991). LMW–GS plays an important role in determining the quality of durum wheat pasta (Pogna et al., 1988). There is a limited amount of information on the relative impact of different B–type LMW–GS on the quality of wheat bread (Gupta et al., 1989; Luo et al., 2001). On the other hand, Masci et al.,
(1998) suggest that one of the most important factors for C–type and D–type LMW–GS is the number of cysteine residues that affect the formation of intermolecular disulfide bonds, so that the LMW–GS can participate in reactions of propagation and termination of the protein chain, leading to an increase of the protein macromolecule.

The Combined Influence of HMW–GS and LMW–GS

In addition to testing the individual HMW–GS and LMW–GS influence on the technological quality of wheat, some studies tested their combined impact as well. The influence of HMW and LMW glutenin subunits on dough properties, i.e., strength and elasticity, can be additive or synergistic (Beasley et al., 2002). By adding LMW–GS and HMW–GS to wheat flour, it was found that when combined, they have a different influence on dough extensibility, from the one when being used separately. This is expected because LMW–GS affects the extensibility when used individually (Luo et al., 2001), whereas HMW–GS has influence on dough elasticity (Payne et al., 1984). Unlike Luo et al., (2001), Verbruggen et al., (2001) found that the addition of LMW–GS to flour/dough significantly lowers the maximum resistance and dough extensibility determined by Kieffer method. On the other hand, HMW–GS causes a significant increase of the maximum resistance of dough. Also, their synergistic operation explains 55% of extensographic indicator value variations (Gupta et al., 1991) and up to 61% of alveograph indicator value variations (Khelifi and Branlard, 1992).

The Influence of Gliadins

It is believed that the monomeric gliadins act as plasticizers of the glutenin polymer system and thus provide plasticity/viscosity of wheat dough (Khatkar et al., 1995). Although the specific composition of gliadin subunits and its contribution in determining the quality of wheat is still not fully known (Metakovsky, 1991), many studies have come to different findings. Contrary to the elastic nature of gluten, it has been proved that the gliadins are viscous and affect the dough extensibility (Payne et al., 1984). Adding gliadin fractions to wheat flour significantly reduces the maximum resistance and increases the dough extensibility (Schropp and Wieser, 1996), which is expected, given their viscous nature. On the contrary, Sozinov and Poperelya

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(1980) found that certain groups of gliadin are in correlation with baking properties, while the study by Huebner et al., (1997) proved that the amount of γ-gliadin of hard red winter wheat is positively correlated with the volume of bread. Similar findings were reported by Gil-Humanes et al., (2012), who found that the contents of γ-gliadin positively correlated with the development of dough (measured by Mixolab), which contributes to the dough strength. The results obtained in this study indicated that γ-gliadins are not the most important indicators of dough quality because their impact varies depending on the composition of other gliadins. Also, it was proved that there are significant statistical links between baking quality and relative contents of certain types of gliadin in wheat varieties of the same glutenin subunit composition (Glu A1 –; Glu B1 7 and Glu D1 2 + 12), and that with the share of just four subunits, 82% variation in bread volume can be explained (Van Lonkhuijsen et al., 1992). Metakovsky et al., (1990) concluded that the gliadins under the control of 6A chromosome correlate with dough resistance, while the gliadins under the control of 6D chromosome correlate with dough extensibility. Although it was previously mentioned that the gliadins are associated with certain indicators of technological quality, Gianibelli et al., (2001) believe that their impact on dough strength is almost inconsiderable. The reason for the contradictory results can be explained by the fact that gliadins have extensive genetic polymorphism (Wrigley et al., 1982), making it much harder to examine the effects of gliadin subunit composition on the technological quality of wheat.

The Combined Influence of Glutenins and Gliadins

Given that gliadins and glutenins have different functions in the highly elastic wheat flour gluten network, the ratio of glutenin and gliadin (glu/gli) is an important parameter which affects the rheological properties of dough and baking properties of flour. Changes in the value of glu/gli relations have a complex effect on dough extensibility, indicating that gliadins and glutenins have completely different effects on this characteristic (Singh et al, 1990; Uthayakumaran et al, 2001). Higher glu/gli values contribute to greater strength of dough (MacRitchie, 1985) and have a significant impact on the quality of loafed bread (MacRitchie, 1987). The research by Edwards et al., (2001) indicates that the increase in the relative content of gliadin is associated with increasing extensibility of dough, as well as reducing dough strength. Similar conclusions were reported by Uthayakumaran et al., (2001), but they...
found that increasing the amount of gliadin leads to a reduction of kneading dough time and maximum resistance, ratio between maximum resistance and extensibility and the loaf height. In order to produce a loaf of good quality, it is necessary to find balance between the viscosity and elasticity of the dough/dough strength, which can be influenced by proper ratio between gliadin and glutenin. Increasing the dough strength will increase the volume of bread only to certain limits, and when the dough becomes too strong, its growth will be stopped.

**IDENTIFICATION OF SUBUNITS OF GLUTEN COMPLEX BY USING DIFFERENT ANALYTICAL TECHNIQUES**

Analytical techniques such as liquid chromatography or electrophoretic techniques are applied for the analysis of wheat proteins for the purpose of their more complete identification (Lookhart, 1991). It is necessary to point out that there is no system for the characterization of gluten proteins which would enable the identification of all protein subunits of the existing wheat genotypes. Two most commonly used electrophoretic techniques used in the analysis of wheat proteins are acidic (A, Acid) – polyacrylamide gel electrophoresis (PAGE, Polyacrylamide Gel Electrophoresis) and sodium dodecyl sulfate (SDS), polyacrylamide gel electrophoresis (PAGE). SDS–PAGE separates protein components on the basis of their size and it has proved to be successful in separating glutenin subunits of high molecular weight (HMW–GS) that are important for the baking properties of flour (Menkovska et al., 2002).

A lot of effort has been made to develop more sophisticated methods such as capillary gel electrophoresis (SDS–CGE, Sodium Dodecyl Sulfate – Capillary Gel Electrophoresis). In recent years it has been proved that the capillary electrophoresis (CE, Capillary Electrophoresis) can be used successfully for separation of all protein types, which has led to its more significant applications. In the past decade, much attention has been paid to the development of microfluid or Lab-on-a-Chip (LoaC) devices and their application in sensitive chemical and biological analyses. LoaC techniques, used for the analysis of proteins, enable separation, dyeing, decolorization and fluorescent detection in a single step, providing the data analysis as well. The advantage of this technique is the use of an extremely low amount of toxic...
chemicals, thus increasing safety and, at the same time, it is possible to determine the protein size in the test matrix, as well as its quantification based on the internal standard. In terms of sensitivity, accuracy in determination of molecular weight and reproducibility, the use of this technique in protein analysis can be compared to SDS–PAGE, which uses comazi brilliant blue for coloring (Kuschel et al., 2002). LoaC technique is based on the principle of non-covalent bonding of fluorescent colors to SDS–protein complexes which are stored on the chip. The absolute accuracy of quantification and the reproducibility of protein determination with the LoaC technique have been improved in comparison to SDS–PAGE and are comparable to the methods for protein determination, such as Lowry and Bradford. LoaC technique has additional advantages compared to SDS–PAGE: it quickly and effectively separates different analytes ranging from small ions to large molecules; it enables numerous repetitions by using small amounts of reagents and thus achieving better results (Kuschel et al., 2002); during the analysis of wheat and flour it is possible to analyze 10 samples in just 10 minutes, using a very small sample – 10 mg (Uthayakumaran et al., 2005).

In addition to the application for testing various complex biological matrices, LoaC technique has also been applied for testing protein wheat. Uthayakumaran et al., (2006) used LoaC electrophoresis with protein kit 200+ for wheat lines analysis. They determined the molecular weight of the subunits that could not be determined by SDS–PAGE. Similarly, Rhazi et al., (2009) used the LoaC electrophoresis with kit 90 and obtained slightly higher values (5-20%) for molecular weight HMW–GS. It was expected to have different molecular weight sizes because the kits used for measurement had different standards for calibration curves used for determining the molecular weight. Also, this study found that the quantification of HMW–GS is highly reproductive, and that it can be used for determining changes in the relative amounts of individual HMW–GS. While analyzing the HMW–GS subunits of three different Austrian varieties, Marchetti–Deschmann et al., (2011) found that intra-chip reproducibility of time corrected area (% of area) of one cultivar ranged from 8.3 to 76% CV (coefficient variation), whereas inter-chip reproducibility of time corrected area (% of area) was higher, ranging from 15.2 to 112.9% CV. Also, Balázs et al., (2012) stated that relative standard deviation (RSD) of peak areas of wheat proteins was 19.03%. Moreover, during examination of one cultivar, Živančev et al., (2013) found that intra-chip reproducibility of HMW–GS quantity expressed as ppm through internal standard ranged from 0.7 to 11.1% CV, whereas inter-chip reproducibility of HMW–GS ranged from 5 to 17.6%. Results obtained in the study for
individual HMW–GS subunits by Rhazi et al., (2009), expressed as a percentage of the surface in relation to the total area of HMW–GS subunits, were very similar to the data obtained by RP–HPLC (Reversed Phase – High Performance Liquid Chromatography). Statistical analysis of results showed that there are no significant differences between the two techniques. On the contrary, Živančev et al., (2015) reported that the relative amount of all HMW–GS gained by RP–HPLC method were higher in comparison to LoaC technique except in the case of glutenin subunit 2*. Also, in most cases the CVs of HMW–GS gained by RP–HPLC were lower than those gained by LoaC method. Furthermore, LoaC technique possesses an advantage in determination of HMW–GS in two cases. Namely, by using RP—HPLC method it was not possible to separate subunit 5 from subunits 8 and 9 of two different samples of wheat cultivars. On the contrary, during the examination of two different sets of wheat cultivars (Croatian and Serbian), Torbica et al., (in press) reported that quantification of gluten protein fractions (% α+γ subunit, % ω subunit, % HMW-GS, % LMW–GS and % HMW/LMW) performed by LoaC technique was better for grouping genetically similar wheat cultivars than quantification of proteins separated by their different solubility by RP-HPLC.

However, it is still relatively difficult to find studies where LoaC technique was used to examine wheat gluten proteins, technological quality of wheat, as well as their relationship. In one of such rare studies by Živančev et al., (2016), the statistical analysis showed different ratios of glutenin and gliadin subunit, whose molecular weight ranges were: <40.000, from 40.000 to 80.000, from 81.000 to 120.000, and> 120000, and it was pointed out that the year of production and the varieties did not have a significant effect on the percentage ranges for glutenins. On the other hand, they had a considerable influence on the percentage ranges for gliadins. Also, HMW–GS composition and climatic conditions revealed that all eight samples of wheat varieties with HMW–GS composition 2*5 + 10, 7 + 9 produced in the year 2011 grouped in two clusters with the best technological quality of wheat. In contrast to them, Zhang et al., (2014) examined deletion of HMW–GS by using LoaC and their influence on gluten properties and Chinese steamed bread quality. They showed that it is possible to gain good dough properties for steamed bread by deletion of HMW–GS at Glu–B1y and/or Glu–D1y loci in high-strength hard wheat. Therefore, this chapter aims to examine the possibilities of applying LoaC techniques for testing gluten protein as well as the connection of the results obtained with the parameters of technological quality of wheat and wheat flour baking properties.
Qualitative Analysis of Gliadin and Glutenin Subunits

In this study, the LoaC analysis included the removal of albumins and globulins from wheat flour samples (n = 18), cultivated for three years. This was carried out using two consecutive extraction processes with two different solvents: deionized water and 2% salt solution. Each time a volume of 300 μl of the solvent was mixed with the flour sample on a vortex mixer for 10 s, and after 24 h extraction period at room temperature, centrifuged for 20 min at 14500 r/min. Extraction was then performed with 70% ethanol solution to form the gliadins. 200 μl of the supernatant of gliadin were separated and left to evaporate the solvent, in order to obtain a pure gliadin precipitate. The remaining pellet sample and a pure flour gliadin precipitate had 200 μl of 2% SDS solution (treatment buffer) added. It contained 5% β-mercaptoethanol, used for the extraction of gluten subunits and denaturation of gliadin and glutenin subunits. After the addition of treatment buffer, the residue of the sample flour is mixed using a mixer at high speed (vortex) for 10 s, and all the samples were heated at 100 °C in water bath for 5 minutes in order to achieve complete denaturation. After heating, 150 μl of SDS solution was added, and the samples were then rapidly mixed (vortex) for 10 s. In this way, solutions with gliadin subunits were prepared for analysis, whereas the samples with glutenin extract were centrifuged for 20 min at 14500 r/min, and the supernatant was used for analysis of glutenin subunits.

After LoaC analysis there have been identified 29 different gliadin and 31 glutenin subunits, via protein kit 230 (Table 3). As proposed by Bhandari (2008), three different ranges of gluten subunits exist on wheat kernel: α, β and γ Gliadins (from 29 to 96 kDa), ω gliadins and LMW Glutenins (from 121 to 129 kDa) and HMW Glutenins (from 131 to 240 kDa). In gliadin extracts there are fourteen subunits identified from the first group, three from the second group and five from the third group, whereas in glutenin extracts there are fourteen subunits identified from the first group, two subunits from the second group and eight subunits from the third group. HMW–GS 12, 9, 8, 10, 7 and 2* have average molecular weight of 131, 133, 139, 148, 184 and 218 kDa respectively, whereas HMW–GS 2 and 5 possess the same molecular weight of 240 kDa. Molecular weight HMW–GS of 2, 5, 7, 10 and 8 were in the upper range set by the Marchetti–Deschmann et al., (2011), while the molecular weight of the HMW–GS 2*, 9 and 12 were outside of the scope designated by the Marchetti–Deschmann et al., (2011). LoaC technique has a disadvantage
because when analyzing glutenin units for varieties that have a combination of HMW–GS 7 + 9 and 2 + 12, in many cases it cannot separate HMW–GS 9 from HMW–GS 12, because their retention times are close. Also the largest HMW–GS 2 and 5 subunits overlap with the upper marker of 240 kDa, so that only a qualitative analysis of these subunits can be done, but not the quantitative analysis.

Table 3. Gliadin and glutenin subunits obtained by LoaC analysis and their size in kDa

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CONNECTIONS OF GLUTEN PROTEINS WITH TECHNOLOGICAL QUALITY OF WHEAT

After the qualitative analysis of gliadin and glutenin subunits, manual integration of individual glutenin subunits has been done. The recorded values of time corrected area for each individual gluten subunit are expressed in percentage in relation to the total area. The results were statistically analyzed to obtain the relationship between HMW–GS (from glutenin extract) and the parameters of technological quality, and ω gliadins (from gliadin extract) and the parameters of technological quality, due to the aforementioned significant impact that these subunits have on the technological quality. The following technological properties of wheat dough and flour have been investigated: falling number, test weight, protein content, farinograph, extensograph and amilograph; alweograph and mixolab; starch damage of flour by amperometric method, wet gluten content, dry gluten content, gluten index and modified gluten index according to Torbica et al., (2007), content of free SH– according to Tomić et al., (2013) in gluten and NH– groups according to Janić Hajnal et al., (2014) in gluten, bread volume, color of bread crust and Texture Profile Analysis (TPA).

CONNECTIONS OF Ω GLIADINS SUBUNITS WITH TECHNOLOGICAL QUALITY OF WHEAT

Table 4 shows the statistically significant correlation coefficients (P ≤ 0.05) for subunit ω gliadins (from gliadin extract) and parameters of technological quality. It was found that the proportion of ω gliadins subunits of 125 and 129 kDa is in positive correlation with the Extensibility (mm) by Extensograph. Also, the proportion of ω gliadins subunits of 129 kDa was positively correlated with L, which is consistent with the research by Payne et al., (1984), who found that gliadins affect dough extensibility. Unlike the research by Gil–Humanes et al., (2012), where it was found that the content of γ-gliadin positively correlated with Dough resistance (min) by Mixolab, the gained results showed that the proportion of ω gliadins subunit of 125 kDa positively correlated with this parameter as well as the parameters of starch component β, Hot paste stability equivalent and starch retrogradation determined by Mixolab. Furthermore, the proportion of ω gliadins subunits of 129 kDa positively correlated with the content of wet gluten content (%) and

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dry gluten content (%), while the share of ω gliadins subunits of 125 kDa positively correlated with parameters of TPA analysis of the bread inside (springiness, cohesiveness and resilience).

Table 4. Correlation coefficient of ω gliadins subunits and technological parameter of wheat

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The Possibility of Utilization of LoaC Technique for Detection …

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Values in bold are different from 0 with a significance level alpha = 0.05.

**Conections of HMW-GS with Technological Quality of Wheat**

The influence of HMW–GS 2 and 5 on the technological quality of analyzed samples is not shown, because a quantitative analysis of these subunits has not been done. It should also be had in mind that only 4 varieties with HMW–GS 2* have been analyzed, which indicated that this subunit has only statistically significant positive correlation (P≤0.05) with the content of damaged starch (AACC 76–31 KSDAM) (Table 5). HMW–GS 12 had the most influence on technological properties of wheat starch component, and statistically significant negative correlation was found for it (P≤0.05) with Falling Number, Viscosity peak by Amilograph and starch retrogradation by Mixolab. On the other hand, HMW–GS 12 significantly positively correlated with the Degree of softening and negatively with P, indicating that the increase of the share of this subunit produces less quality dough. The results are consistent with research by Lafiandra et al., (1993), who found that wheat varieties with a combination of HMW–GS 2 + 12 have less quality dough. In addition to these influences, a share of HMW–GS positively correlated with red color tone (a*) and the springiness of the bread crumb.
Table 5. Correlation coefficient of HMW–GS and technological parameter of wheat

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<td>Amino groups 0’ µg/kg</td>
<td>0.6038</td>
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<tr>
<td>Amino groups 30°C 135’ µg/kg</td>
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<td>Amino groups 37°C 135’ µg/kg</td>
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<tr>
<td>L*(D65)</td>
<td>0.3320</td>
<td>0.5117</td>
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<tr>
<td>a*(D65)</td>
<td>-0.3809</td>
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<tr>
<td>b*(D65)</td>
<td>0.4256</td>
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<td>bread volume (cm³)</td>
<td>0.2749</td>
<td>0.4256</td>
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<td>Hardness g</td>
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<td>Springiness</td>
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<td>Resilience</td>
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Values in bold are different from 0 with a significance level alpha=0.05.

The share of HMW–GS 9 has a statistically significant (P ≤ 0.05) positive correlation with the test weight, development time by farinograph, as well as the content of free –SH content at 30°C 0’mg/kg wet gluten content and free NH at 37°C 135’ µg/kg gluten (Table 5). Statistically significant (P ≤ 0.05) positive correlation between the HMW–GS 9 and the last two parameters indicate that HMW–GS 9 in itself has a higher content of free –SH content, as well as that during the incubation at 37°C for a time of 135’ there has been detected a disturbance of the primary structure of the protein of this subunit. Although the proportion of HMW–GS 8 is in statistically significant (P ≤ 0.05)
positive correlation with the Stability by farinograph, Dough development time, β and γ by Mixolab (Table 5), these correlations cannot be taken as reliable, as only one wheat variety with this subunit has been analyzed. Even though the research in Lafiandra et al., (1993) and Huebner et al., (1999) demonstrated that wheat varieties with a combination of HMW–GS 5 + 10 form stronger dough and better cookies than wheat varieties with a combination of HMW–GS 2 + 12, the results indicate that HMW–GS 10 has a negative impact on the technological properties. The statistically significant negative (P ≤ 0.05) correlations were obtained between the proportion of HMW–GS 10 and protein content, and W (Table 5). This can be explained by the fact that x–type subunits have a greater effect on the dough indicators than the subunits of y–type (5 and 2 compared to 10 and 12) (Anderson and Bekes, 2011); although the proportion of HMW–GS 5 could not have been determined, this subunit has a much greater positive impact on the quality of dough than HMW–GS 10. Also, the proportion of HMW–GS 10 had a statistically significant positive (P ≤ 0.05) correlation with the test weight, L* and b*, but negative correlation with hot paste stability equivalent. HMW–GS 7 had the same effects as the HMW–GS 10 on the previously mentioned parameters, only the effect was much more pronounced (Table 5), since the values of correlation coefficients were higher (for example, 0.3121, 0.3320, 0.2749, -0.2786 and 0.5599, 0.5117, 0.4256, -0.6225 respectively). In addition, the results showed that HMW–GS 7 had the greatest influence on the parameters of technological quality, because all the tested varieties contained this subunit. HMW–GS 7 had a negative impact on a significant number of parameters that define dough strength: Water absorption by farinograph, P, extensibility by extensograph, wet gluten content, dry gluten content, free – NH content at 0’ and 37°C 135’ µg/kg gluten (statistically significant negative (P ≤ 0.05) correlations) and α mixolab (statistically significant positive correlation), and positive for only three: Resistance by Extensograph, ratio Resistance and Extensibility by Extensograph and GI (statistically significant positive (P ≤ 0.05) correlation). Furthermore, HMW–GS 7 had a negative impact on the amylolytic activity of wheat varieties: Falling number, Viscosity peak by Amilograph and C3 by Mixolab (statistically significant positive correlation) and also influenced the other parameters of starch component: starch retrogradation by Mixolab and UCDc KSDAM (statistically significant negative correlation). It is important to note that HMW–GS 7 had statistically significant (P ≤ 0.05) correlation with the parameters of bread crust color. The increasing use of these subunits produced bread with the lighter crust, with
more yellow and less red tone, which is associated with amylolytic activity of wheat varieties.

**CONCLUSION**

Finally, it could be concluded that proportion of $\omega$ gliadins subunits of 125 and 129 kDa is in statistically significant positive correlation with dough extensibility. Also, HMW-GS 7 had the greatest influence on the examined parameters of technological quality of wheat, because all the tested varieties contained this subunit, while the influence of the HMW-GS 2* and 8 could not be fully examined due to the insufficient number of analyzed varieties. Therefore, in order to reach a more reliable conclusion it is necessary to carry out additional research, including a larger number of cultivars that contain the HMW-GS. Furthermore, it should be emphasized that although LoaC technique possesses a few mentioned advantages, it also has certain disadvantages, such as overlapping HMW-GS 9 and 12 as well as 2 and 5 subunits with the upper marker; it might be overcome if manufactures of equipment produced adequate protein kits.

**ACKNOWLEDGMENTS**

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Chapter 5

DAIRY FARM MANAGEMENT STRATEGIES TO REDUCE GREENHOUSE GAS EMISSIONS: MITIGATION STRATEGIES AND ECONOMIC CONSIDERATIONS IN THE US

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Department of Dairy Science,
University of Wisconsin-Madison, Madison, WI, US

ABSTRACT

Effective greenhouse gas (GHG) mitigation strategies lead to win-win situations of reducing GHG emissions while improving productivity and likely farm profit (Hristov et al., 2013; Liang and Cabrera, 2015). This chapter discusses several dairy farm management strategies that can be manipulated to reach such win-win situations. These include: 1) nutrition (diet formulation, feed efficiency, feed additives, and grazing management), 2) genetics and culling, 3) manure management, and 4) reproduction and health. The general effect of direct GHG gas mitigation strategies can be visualized in Figure 1.

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Forage-to-concentrate ratio. Both of forage and concentrate have high content of carbohydrates. The difference between them is that forage has higher neutral detergent fiber (NDF) whereas concentrate has higher non-fiber carbohydrates (NFC) content. Carbohydrate type in the ration influence enteric CH$_4$ productions by changing rumen pH and microbial population. The relationship between dietary composition and CH$_4$ emissions is discussed in Moe and Tyrrell (1979) and Jentsch et al., (2007), listed in Table 1. Non-fiber carbohydrates and NDF have different fermentation patterns in the rumen, which affect rumen volatile fatty acid (VFA) profile in the fermentation end products (Moe and Tyrrell, 1979; Johnson and Johnson, 1995a; Knapp et al., 2014). Moss et al., (2000) summarized the relationship between different VFA and CH$_4$ production as the equation listed in Table 1. Greater acetate and butyrate synthesis promotes enteric CH$_4$ production whereas greater propionate decreases CH$_4$ emission by influencing hydrogen equivalent. Acetate and butyrate formation from hexose produces hydrogen that promotes methanogenesis. Propionate formation is competitive with methanogenesis in H (Hungate, 1966). Feed ingredient will promote CH$_4$ production if it ferments more into acetate or butyrate. Neutral detergent fiber is composed of cellulose, hemicellulose, and lignin. Hemicellulose has higher digestibility than cellulose.
in ruminant animals (Keys et al., 1969). Same amount of hemicellulose produces much less CH$_4$ compared with cellulose because it ferments into more propionate (Moe and Tyrrell, 1979; Murphy et al., 1982). Non-fiber carbohydrates are majorly starch, sugar, organic acids, pectin, and other reserve carbohydrates (NRC, 2001). Non-fiber carbohydrates favor propionate-genesis microbes during rumen fermentation (Martin et al., 2010; Knapp et al., 2014). In general, lower NDF:NFC (forage-to-concentrate ratio) diet decreases CH$_4$-energy loss as a proportion of gross energy intake (Beauchemin et al., 2008; Martin et al., 2010; Knapp et al., 2014; ). In addition to VFA profile changes, high NFC fermentation decreases rumen pH. High starch diet depresses rumen pH by decreasing chewing activity and saliva buffering, increasing rumen VFA content, and lowering methanogen activities (Russell, 1998; Krause et al., 2002). High NFC diet also increases rumen protozoa density (Franzolin and Dehority, 1996; Hook et al., 2011). Russell (1998) found that cows fed with high concentrate diet had lower rumen pH, higher VFA content, and are lower in acetate: propionate ratio than cows fed all forage diet. Lower pH between the ranges of 5.5 to 6.5 decreases CH$_4$ production by fermenting it into more propionate. When pH drops below 5.5, H$_2$ starts accumulating in the rumen, which further indicates that low pH reduces CH$_4$ production by decreasing rumen methanogenesis in addition to increasing propionate production (Russell, 1998).

High forage-to-concentrate ratio diet normally leads to greater enteric CH$_4$ emission (Murphy et al., 1982). Aguerre et al., (2012) tested the effect of forage-to-concentrate ratio on enteric CH$_4$ emission. Results showed that increasing forage proportion increased CH$_4$ production, increased rumen pH linearly, and increased butyrate concentrate quadratically. Substituting forage with concentrate in the diet increases protein and energy intake, which positively correlates with milk production. Decreasing forage-to-concentrate ratio can increase milk production and reduce rumen enteric CH$_4$ emission, both of the effects contribute to lower GHG emission intensity (GHG-EI), which is the GHG emission per kg of fat-corrected milk (FCM) production. Farms that rely heavily on forage intake, such as grazing or organic farms, can increase their productivity and eventually decrease enteric CH$_4$ by providing supplement concentrate to lactating cows, which increases gross energy intake and reduces forage-to-concentrate in diet. Albeit production increases, greater grain content can shrink the profit and therefore supplying more concentration can be a delicate balance (Hristov et al., 2013). Although decreasing forage proportion is beneficial for reducing CH$_4$ emission, this practice can decrease milk fat production.

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Table 1. Relationship between dietary composition and CH4 emission

<table>
<thead>
<tr>
<th>Source</th>
<th>Equation</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Ramin and Huhtanen, (2013)</td>
<td>( CH_4(L/d) = 20(\pm 1.21) + 35.8(\pm 2.87) \times DMI - 0.5(\pm 0.132) \times DMI )</td>
<td>Dry matter intake is the dominating factor. The quadratic term of DMI indicates enteric CH4 emission does not increasing linearly with DMI. High DMI level decreases CH4 per unit of DMI. Greater dietary lipid content (EE) and NFC:NDF ratio reduces enteric CH4 production linearly.</td>
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<td></td>
<td>( CH_4(L/d) = -64.9 (\pm 35.0) + 26.0 (\pm 1.02) \times DMI - 0.61(\pm 0.132) \times cDMI^2 + 0.25 (\pm 0.051) \times OMD_m - 66.4 (\pm 8.22) \times EE - 45.0 (\pm 23.50) \times \left(\frac{NFC}{NFC+NDF}\right) )</td>
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<td>Moraes et al., (2014)</td>
<td>( CH_4(MJ/d) = -9.311(\pm 1.060) + 0.042(\pm 0.001) \times GEI + 0.094(\pm 0.014) \times NDF - 0.381(\pm 0.092) \times EE + 0.008(\pm 0.001) \times BW + 1.621(\pm 0.119) \times MF )</td>
<td>Animal level model. Gross energy intake is the dominating factor. Body weight, NDF, and milk fat positively relate with enteric CH4 emission. Greater dietary lipid content (EE) reduces enteric CH4 production linearly.</td>
</tr>
<tr>
<td>Moraes et al., (2014)</td>
<td>( CH_4(MJ/d) = 0.225(\pm 0.713) + 0.042 (\pm 0.001) \times GEI + 0.125 (\pm 0.015) \times NDF - 0.329 (\pm 0.094) \times EE )</td>
<td>Dietary level model. NDF positively relates with CH4 emission. Greater dietary lipid content (EE) reduces enteric CH4 production linearly.</td>
</tr>
<tr>
<td>Moraes et al., (2014)</td>
<td>( CH_4(MJ/d) = 0.3247(\pm 0.429) + 0.043 (\pm 0.001) \times GEI )</td>
<td>Gross energy level model. Gross energy is dominating in the prediction.</td>
</tr>
<tr>
<td>Moss et al., (2000)</td>
<td>( CH_4 = (0.45 \times acetate - 0.275 \times propionate + 0.40 \times butyrate) )</td>
<td>Enteric methane emission positively relates with ruminal acetate and butyrate content; negatively relates with propionate content.</td>
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<td>Moe and Tyrell (1979):</td>
<td>( CH_4(\text{NDF}) = 0.439 + 0.273(\pm 0.015) \times \text{digested soluble residue} \left(\frac{k_g}{d}\right) + 0.512 (\pm 0.078) \times \text{digested hemicellulose} \left(\frac{k_g}{d}\right) + 1.393 (\pm 0.097) \times \text{cellulose} \left(\frac{k_g}{d}\right) )</td>
<td>Cellulose is about 2.5 times more CH4-favor than hemicellulose.</td>
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<td>Jentsch et al., (2007):</td>
<td>( CH_4(kf) = 1.28 (\pm 0.21) \times \text{digestible crude protein} \ (g) - 0.31 (\pm 0.53) \times \text{digestible curd fat} \ (g) + 1.31 (\pm 0.09) \times \text{digestible starch} \ (g) + 1.16 (\pm 0.18) \times \text{digestible sugar} \ (g) + 2.40 (\pm 0.08) \times \text{digestible N - free residuals (NFR)} \ (g) )</td>
<td>Digested feed composition relates to CH4 emission more closely than total composition. Free residual indicates that feed efficiency and CH4 emission may be related and need more research.</td>
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</table>
Pasture and grazing management. Pasture and grazing management includes selecting forage species and ensuring its optimal quality (maturity), which affects CH$_4$ emission by changing NDF digestibility. Archimède et al., (2011) found that C4 grass led to the greatest CH$_4$ emission (33.7 L CH$_4$/kg dry matter intake, DMI) and legume in warm climate emitted the least CH$_4$ (25.9 L CH$_4$/kg DMI). C3 grass (30.0 L CH$_4$/kg DMI) and legume in cold climate (30.1 L CH$_4$/kg DMI) are the moderate ones and not different from each other in emission. Forage maturity influences CH$_4$ production: more mature forage has greater lignin content. More mature forage decreases NDF digestibility (Moss et al., 2000; Boadi et al., 2004b). Jung and Allen (1995) found that C4 grass (with higher lignin content) produces more CH$_4$ during fermentation than C3 grass (low lignin content). Lignification in C4 grass makes it harder to digest and increases CH$_4$ production. Robertson and Waghorn (2002) reported that CH$_4$ emission of grazing cows increased by 11.1% (361 g to 401 g CH$_4$/cow/d) when pasture matured from September (Spring) to December (Summer) in New Zealand. Choosing appropriate forage feed ingredient and monitoring the maturity (during harvesting or grazing management) help decrease the lignin content and further reduce CH$_4$ emission during fermentation. Ensiling could increase butyrate content in haylage compared with dry hay without ensiling (Shingfield et al., 2002), however more research is needed in the mechanism.

Corn silage and grass silage are the two common types of silage used in dairy farming. Compared with corn silage, grass silage favors enteric CH$_4$ production because its higher fiber digestibility, which leads to higher rumen pH, greater ruminal protozoa density, and higher acetate: propionate ratio in end products (VFA) (Hassanat et al., 2013). Replacing alfalfa silage with corn silage is a good way to reduce enteric CH$_4$, however, too much corn silage may cause rumen acidoses.

Increasing DMI. Several decades ago, research already demonstrated that enteric methane production is positively related to DMI or digestible energy (Blaxter and Clapperton, 1965; Moe and Tyrrell, 1979; Murphy et al., 1982). Greater DMI requires larger rumen capacity that enables longer feed retention time in rumen and increases the digestion rate; larger rumen volume elevates the time microbial working on fibers and leads to greater CH$_4$ emission (Pinares-Patio et al., 2003). The absolute CH$_4$ production increases as DMI increases, however, the ratio of CH$_4$-energy to total energy intake decreases as DMI increases (Jentsch et al., 2007; Ramin and Huhtanen, 2013). As feed intake energy increases, energy loss to CH$_4$ production decreases.
approximately 10% for every increase of multiple of maintenance energy (Ramin and Huhtanen, 2013).

Meta-analysis conducted by Ramin and Huhtanen (2013) and Moraes et al., (2014) agree that dietary intake level (DMI or gross energy intake, GEI) is the dominating variable in enteric CH$_4$ emission prediction (Table 1). Increasing dietary energy intake or DMI will increase enteric CH$_4$ emission. However, the energy loss to CH$_4$ as a proportion to GEI (CH$_4$-energy/GEI) reduces as feeding energy level increases (Ramin and Huhtanen, 2013). The results indicate that CH$_4$ emission increases nonlinearly with increasing in feed intake level: it increases faster when DMI (or GE intake) is low, then the increasing rate slows down as DMI (or GEI) keeps increasing. Dry matter intake level is also closely and positively related with milk production (NRC, 2001). Assuming the feed efficiency stays the same, greater DMI (or GEI) increases milk production linearly and increases enteric CH$_4$ emission nonlinearly. Therefore, enteric CH$_4$ emission per kg of milk will be lower at higher feed intake level. Hence, higher DMI has the advantage to increase production and relatively reduce CH$_4$ emission per unit of feed intake or milk production (Johnson and Johnson, 1995a; Pinares-Patino et al., 2009).

Increasing intake elevates milk productivity and decreases the proportion of enteric CH$_4$-energy to gross energy intake and further reduces CH$_4$ emission per kg of energy corrected milk (ECM) produced (Johnson and Johnson, 1995b; Capper et al., 2009; Yan et al., 2010). Therefore, high-producing cows are preferred for reducing CH$_4$ emission. In addition, fewer cows are needed to feed the same population, which further reduces CH$_4$ emission. Defined as the ratio of ECM over DMI, higher feed efficiency promotes higher milk production over the same amount of feed resource maintaining or decreasing land demand and feed expenditure. Higher feed efficiency reduces land demand and GHG emissions from all sources (enteric fermentation, manure and soil, energy use, fertilizer production, and concentration production; Bell et al., 2011). Greater feed efficiency also decreases nitrogen, phosphorus, and potassium excreted in manure because of lower intake and better usage of feed (Boadi et al., 2004).

**Dietary crude protein level.** Dietary crude protein (CP) is positively correlated with manure N content. It is known that increasing dietary N content would increase N$_2$O emission from manure storage due to greater N concentrate in manure (Montes et al., 2013a). Dietary CP content changes manure VFA content and NH$_3$ emission from manure, both of them are inhibitors of CH$_4$ production from manure (Hansen et al., 1998; Møller et al., 2004). Nitrogen in urine has larger impact on manure N$_2$O emission than...
nitrogen in feces. Kuelling et al., (2001) found that increasing dietary CP content might decrease CH\textsubscript{4} emission from urine-rich slurry manure storage and had no effect on CH\textsubscript{4} emission from other manure storage type (slurry or solid storage). Crude protein in diet positively relates with fiber digestibility; higher dietary CP has the potential to reduce enteric CH\textsubscript{4} emission by increasing fiber digestibility (Knapp et al., 2015). However, increasing dietary CP content to reduce CH\textsubscript{4} emission from rumen and manure is not an efficient GHG mitigation strategy. High CP diet leads to higher N in manure, which results in significantly higher NH\textsubscript{3} and N\textsubscript{2}O emission from manure during storage and after land application. Manipulating dietary CP content is an effective way to reduce manure N\textsubscript{2}O emission by decreasing exceeding N content in manure. Lower CP content in diet has the potential to increase CH\textsubscript{4} emission from enteric fermentation and slurry manure (Külling et al., 2002; Dijkstra et al., 2011). The overall effects of increasing dietary CP content has to be evaluated including both N\textsubscript{2}O and CH\textsubscript{4} emissions from enteric fermentation, manure management, and land application.

**Dietary lipid level.** Research has focused on the effect of dietary lipid on reducing enteric CH\textsubscript{4} emissions. Greater dietary lipid reduces methane production through the following three mechanisms: 1) affecting fermentation substrates and increasing propionate in the VFA profile; 2) suppressing rumen methanogens population in vivo and ciliate protozoa in vitro; and 3) unsaturated fat using metabolic hydrogen in bio-hydrogenation to reduce the hydrogen equivalent of metabolic hydrogen (Hook et al., 2010; Beauchemin et al., 2008b; Knapp et al., 2014). Fatty acids (FA) have direct toxic on methanogens; however, the mechanism remains unclear. McAllister et al., (1996) and Giger-reverdin et al., (2003) suggested long-chain FA had toxic to methanogens, however, more recent studies indicated that medium-chain FA had toxic to methanogens, not the long-chain FA (Martin et al., 2010). Prediction models in Table 1 show that dietary ether extract (EE) content negatively relates with enteric CH\textsubscript{4} emission.

Different feed source of lipid reduced enteric CH\textsubscript{4} production in different ways by different FA profile in those feed ingredients. Beauchemin et al., (2009) found that crushed flex seed and sunflower seed decreased CH\textsubscript{4} emission by reducing DMI and digestibility at some extent; meanwhile crushed canola seed reduce CH\textsubscript{4} not affecting DMI. Palm kernel oil, coconut oil, and one type of canola oil are able to reduce the density of methanogens, ciliates, and methane emissions (Dohme et al., 2000). Dohme et al., (2001) found that some median-chain saturated FA (C12:0 and C14:0) have negative effect on CH\textsubscript{4} release. In addition, unsaturated long-chain FA (C18:1 from
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Rapeseed (C18:2 from soybean and sunflower oil, and C18:3 from linseed) also depress methane production (Dohme et al., 2001; Martin et al., 2010). According to Martin et al., (2010), increasing 1% of C18:1, C18:2 and C18:3 in the diet, decrease CH$_4$ release by 2.5%, 4.1%, and 4.5%, respectively; CH$_4$ depression by one additional percent of C16 or C18 (from tallow) saturated FA is 3.5%.

Unsaturated FA is able to uptake metabolic hydrogen in the rumen to reduce the equivalent. This bio-hydrogenation process is trivial in reducing hydrogen amount because 1 mol of C18:1 (linoleic acid) only utilize 2 mol of H$_2$, which reduced 1 mol of CH$_4$ (Ramin and Huhtanen, 2013). Polyunsaturated FA has negative effect on protozoa and cellulolytic bacteria, therefore increasing polyunsaturated FA would shifts rumen fermentation to produce more propionate (Doreau and Ferlay, 1995; Martin et al., 2010).

Beauchemin et al., (2008) conducted a meta-analysis and reported 1% more supplement fat decreased 5.6% of CH$_4$ (g/kg DMI). Another meta-analysis by Eugène et al., (2008) suggested that 6.7% dietary EE content decreased CH$_4$ emission (MJ/d) by 9% comparing with 2.2% EE content. Martin et al., (2010) summarized the effect of lipid on CH$_4$ emissions to have 3.8% decrease in CH$_4$ per percent increase in dietary lipid content. Dietary lipid type and rumen availability are important in the effect on CH$_4$ production (Martin et al., 2010). Mitigation strategy through increasing dietary lipid content is promising, but the implementation must be under monitoring. Current research has only confirmed short-term CH$_4$ reduction, however failed to demonstrate long-term effect (Woodward et al., 2006; Grainger and Beauchemin, 2011). When rumen microbes adapted to the high lipid feed, effects of adding dietary lipid to reduce enteric CH$_4$ emission subsided. Too much dietary lipid decreased total DMI, NDF digestibility, and diluted the benefits of more intensive energy content brought by greater lipid content (Knapp et al., 2014; Beauchemin et al., 2008; Martin et al., 2010). A reasonable maximum of dietary lipid content should be no greater than 6-7% of total DMI (normally no more than 2-3%, Beauchemin et al., 2008a; NRC, 2001). Dietary mitigation option should be evaluated on a farm level than only focusing on rumen. Adding extra lipid to reduce enteric CH$_4$ emission may reduce the NDF digestibility and change the composition of manure. Methane and N$_2$O emission from manure closely related with manure composition, which is sensitive with the dietary changes.

Feed additives. Some feed additives can reduce enteric CH$_4$ emission. Monensin is a typical feed additive, which is a biologically active compound by a strain of Streptomyces cinnamomensis (Richardson et al., 1976).
Monensin is commonly used to increase feed efficiency while decreasing enteric CH$_4$ production. Monensin pushes the fermentation towards propionate to lower hydrogen supply in the rumen, thus increasing feed efficiency and reducing CH$_4$ release. Richardson et al., (1976) reported that monensin could decrease CH$_4$ emission by increasing acetate:propionate ratio in rumen VFA both in vitro and in vivo. Monensin could decrease rumen microbial growth rate without affecting the amount of fermented substrates (Van Nevel and Demeyer, 1977). However, use of monensin to reduce enteric CH$_4$ is not practical. Beauchemin et al., (2008) summarizes that only high dose of monensin (24-35 ppm) reduces enteric CH$_4$ emission by 4-10% (g per d) and 3-8% (g per kg DMI), lower dose (<20 ppm) is not effective on CH$_4$ reduction. The nearly double-amount high dose will increase feed costs. Another limitation of using monensin is that Europe and other countries prohibit using monensin as feed additive as it is a natural antibiotic.

New technologies in feed additives show the high potential of reducing enteric CH$_4$ emission. A recent study (Hristov et al., 2015) conducted in Pennsylvania found that a methanogen inhibitor, 3-nitrooxypropanol (3NOP), is able to reduce CH$_4$ without reducing milk production in a long-term experiment. Using 3NOP will emit H$_2$ instead of CH$_4$ from the rumen. The results showed 30% reduction in rumen CH$_4$ production. Without doubt, 3NOP could be an excellent approach to reduce GHG emission from dairy farms. Nonetheless, more research is needed on this new product to confirm the results and test the side effects. Economic partial budgeting is also important before using these new products commercially.

**GENETIC SELECTION AND CULLING**

Genetic selection to improve feed efficiency is a long-term mitigation strategy at the farm level (Berry, 2013). Cows selected for higher feed efficiency tend to produce less CH$_4$ (Hegarty et al., 2007). However, due to the low heritability of feed efficiency in dairy cattle, more research is needed to confirm the effect of reducing GHG emission from genetic selection towards higher feed efficiency cows (Waghorn and Hegarty, 2011; Montes et al., 2013b). Selection on the lower enteric CH$_4$ production trait is another mitigation option through breeding. Manipulating ruminal microbial flora, especially methanogens, through breeding approach has also been proposed as a mitigation option (Cottle et al., 2011; McSweeney and Mackie, 2012). Studies have noticed the differences in GHG emission between cow breeds.
Jersey cows may have the advantage of greater feed efficiency than pure Holstein breed due to higher conversion rate of feed to milk fat (Goddard, 2003; Ellis et al., 2007; Halachmi et al., 2011). Gradually decreasing Holstein body size through breeding could also be a potential approach to improve feed efficiency and reduce farm GHG emission.

Whole farm models research found a positive relationship between culling rate and farm-level GHG emission and farm profit (Garnsworthy, 2004; Weiske et al., 2006; Bell et al., 2011; Liang and Cabrera, 2015). Reducing replacement rate by 10% decreases farm-level GHG emission by 2.3% to 3.9% depending on the production system (Weiske et al., 2006). Selling surplus heifer calves for slaughter at young age is a potential option to reduce farm-level GHG emission by raising less replacements on-farm. Weiske et al., (2006) found 4.9-6.7% decreasing in whole farm GHG emission when selling surplus heifer calves at newborn age.

Although higher culling rate would increase GHG emission per kg of ECM, it is possible to turn the aggressive culling into a long-term mitigation option. Milk production per cow per year in the US increased from 2,074 to 9,193 kg (443%) between 1944 to 2007 (Capper et al., 2014). Genetic selection contributes 55% to this tremendous productivity improvement (Shook 2006). Culling and genetic selection result in better productivity. Higher culling rate will accelerate herd turnover, which improves productivity faster. Except selecting for higher efficiency or lower CH₄ production cows, milk production improvement in long term dilutes the GHG-EI because of larger number of heifers raised. In addition to health issue and reproductive failure, economic is a big driver for culling in dairy farms. Higher beef price, high feed price, or low milk price encourages farmers to cull more cows than other market conditions. Farmers get greater revenue or save feed cost by selling their cows. High culling rate results in higher GHG-EI for now, however, the high culling rate with genetic selection has the potential to change the higher short-term emission to lower GHG-EI in the long-term.

**Manure Management**

Manure management determines GHG emission sources and corresponded mitigation strategies. Manure management has to be designed farm-specific. Farm size, housing type, cropping practice, farm location, market availability, financial condition, farm expansion plan, and regulations are all determinant factors in manure management strategies. Housing system and grazing...
management determine how much manure can to be managed or treated. Manure collection efficiency, which represents the proportion of manure can be collected, is higher in free-stall and tie-stall farms compared with dry lot, loose housing, or heavily grazing farms. When cows are on pasture or dry lot, it is merely possible to scrape or flush the manure and put together for storage and/or processing. Dairy farm in the US usually use open lagoon/pit for manure storage then apply to the field when needed. Open lagoon raises the issues of GHG emission and water quality. Research has developed innovative manure management strategies to help with environment concerns. There are many innovative and promising manure management strategies such as covered lagoon with CH4 burning, manure separation and composting, and anaerobic digesters that are discussed below.

Nitrous oxide (N2O) is the major GHG from manure stored in piles (solid) whereas CH4 is the major GHG from slurry-based system (liquid) (Masse et al., 2008; Chadwick et al., 2011; Montes et al., 2013a). Nitrous oxide production requires aerobic environment whereas CH4 requires anaerobic environment. Hence, presence of oxygen shifts the environment to be CH4-favored or N2O-favored. Storage duration and cover formation (natural or artificial, or formed crust) are two influencing factors on manure GHG emission, from manure management standpoint. Shorter storage duration reduces manure CH4 and N2O emission by shorten the nutrient decomposing time (Hou et al., 2015). However, shorten manure storage time may not be realistic. Manure storage duration most likely depends on farm cropping practices. Manure is normally applied to the land no more than twice a year: after harvest in the fall and/or before tillage in the spring. Manure is stored until the next land application time.

Cover on manure storage reduced CH4 emission but increased N2O emission (Sommer et al., 2000). Natural crust or straw cover prohibits CH4 from escaping to the atmosphere; artificial cover further oxidizes some trapped CH4 into CO2. One practical mitigation strategy is to cover the lagoon with impermeable material and burn the trapped CH4 to reduce GHG emission from manure storage. Burning CH4 or use it as cooking gas eventually reduces CH4 emission from storage. Covering lagoon requires investment in the cover and the total cost depends on the design of lagoon; it doesn’t create new benefits other than carbon credits. Covered lagoon can’t reduce manure volume and the farm has to deal with the manure nutrient.

Manure aerated composting is another strategy to reduce emission that goes beyond lagoon covered. First step is to separate manure into liquid and solid parts. Only the solid manure goes into the composting process. Manure is
composted under cover, which traps CH$_4$ from emitting to the atmosphere and reduce CH$_4$ emission. However, NH$_3$ emission during composting is significant (up to 32.4% of N content, Jiang et al., 2011) and the effect of composting manure on reducing N$_2$O emission is not clear yet (Montes et al., 2013a). Different than only covering the lagoon, composting can reduce manure volume almost by half still keeping most of the nutrients. Composting requires extra capital investment including purchasing separator, performing the composting process, and maintenance operations. Composted manure can be used as good soil amendment, such as a garden mix. Local market condition determines the value of composted manure as commercial product; the influencing factors include farm location, consumer demand, shipping cost, among others. Revenue from selling composted manure helps to pay the investment.

Anaerobic digester is an advanced option to reduce manure GHG emission. The minimum herd size for operating anaerobic digester is 500 cows for sufficient manure input and profitability (EPA, https://www.epa.gov/agstar/anaerobic-digestion-right-your-farm). Digester maximizes CH$_4$ production under the anaerobic condition according to specific temperature. Between 49-60°C is the optimal temperature range to facilitate thermophilic bacteria growth, which produce more CH$_4$ than the other methanogens (Ahn and Forster, 2000; Kim et al., 2002). It may not be possible in some cold climate areas where a heating system is needed in the digester. Methane produced in the digester is used to generate electricity or produce natural gas (compressed or liquid), which can be used as fuel to run farm vehicles and milk shipping trucks. Three common digester types are covered lagoon digester, complete mix digester, and plug flow digester. They are different in structure and temperature control. The end product (digestate) of anaerobic digester contains all manure nutrients. Digestate can be used as fertilizer directly, but the farm may need a storage space to keep it and until used. Digestate is a better soil fertilizer than raw manure because it has higher content of inorganic carbon and nitrogen, which are easier for plants up-taking (Marañón et al., 2011).

Building an anaerobic digester is very expensive and not suitable for all farms, especially not for small farms. High initial investment in anaerobic digester requires long time to payback, usually from 4 to more than 10 years according to the financial conditions (Lazarus and Rudstrom, 2007). Electricity price is a dramatic influencing factor on anaerobic digester profitability. In the region with low electricity price, producing natural gas could be a better option than generating electricity from digester. Digester is
able to handle animal manure from nearby farms or local food waste if not at maximum capacity, which may bring some ‘tipping fees’ into the revenue. Advanced technologies have been developed on digestate treatment to maximize the value of digestate. These practices include fiber recovery, nutrient recovery, and water recycling. Recovered fiber or nutrient from digestate can be either used on farm or sold to the market to improve the economic feasibility of anaerobic digesters (Prapaspongsa et al., 2010). In addition, digestate can be used to produce biochar, a promising and high value soil amendment (Matovic, 2011; Wu et al., 2013). Biochar is solid and stores carbon permanently. Applying biochar to the land could improve soil water holding capacity on loam soils and crop productivity, and reduce GHG emission from land (Galinato et al., 2011). Digestate treatment requires extra investment and the market for some end products is not yet common in the US. Economic analysis and financial budgeting are needed before investing an anaerobic digester and following digestate treatment.

Manure management is a promising area to reduce dairy farm GHG emission. Greenhouse gas emission from dairy manure management increased 90.5% from 1990 to 2014, however, the enteric fermentation emission only increased 6.3% during the same period (Figure 2; EPA, 2014). Manure management is different from enteric fermentation in terms of reducing GHG-EI because manure management changes will not affect milk or meat production. Benefits from manure management improvement are hard to quantify meanwhile the initial investment is always high. Improve manure management is not on the top of dairy farmer’s to-do list. Lacking the markets for lower carbon footprint dairy products, composting end products, and digestate products so that the only benefits are from carbon credits, generated electricity (in digester) and natural gas production (some farm produce natural gas if CH$_4$ sufficient in digester), and manure as fertilizer value. Some dairy farmers underestimate the potential cost of current manure management. Farmers without a good manure management plan have a risk of getting involved into environmental litigation suits, which can be very expensive (Davis, 2006). Low revenue and high cost, together with the subjective perception are barriers for dairy farms to change its manure management strategies.
Reproduction and health influence GHG-EI indirectly (Knapp et al., 2014; Hristov et al., 2013; Garnsworthy, 2004). Previous study demonstrated that higher producing herds have lower GHG-EI than lower producing herds (Liang and Cabrera, 2015). Good reproduction and health ensure cows can fully express their genetic potential on productivity. Higher production level dilutes the absolute GHG emission from higher DMI comparing with low-producing level. Herds with good reproduction and health also have lower demand of replacement heifer for involuntary culling due to sickness or breeding failure. Fewer replacement heifer decreases the GHG emission from raising heifers before 1st lactation (Garnsworthy, 2004; Bell et al., 2011; Liang and Cabrera, 2015). Disease and reproductive failure have detrimental effects on milk production, conception time, and longevity, all which lead to greater GHG-EI. Keep good reproduction and herd health are always dairy farmer’s top priority. Mitigating GHG emission from this aspect is in agreement of the farm’s management goals.
REFERENCES


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**Biographical Sketches**

**Dr. Victor E. Cabrera** is an associate professor and extension specialist in dairy management at the University of Wisconsin-Madison Dairy Science Department. Dr. Cabrera combines applied research, interdisciplinary approaches, and participatory methods to deliver practical, user-friendly, and scholarly decision support tools for dairy farm management. These scientific tools are aimed to improve dairy farm profitability, environmental stewardship, and long-term sustainability of the dairy farm industry. During his short career, Dr. Cabrera has developed more than 40 decision support tools, published 55 refereed articles, and 5 book chapters, presented in more than 100 scientific sessions, and given talks in more than 180 extension meetings in Wisconsin, other States, and several other countries. Dr. Cabrera work in the past 5 years has been pivotal to attract more than $3.5 million to support his research and extension initiatives. Dr. Cabrera has been distinguished with Vilas Faculty Mid-Career Investigator Award from the University of Wisconsin-Madison, Second Mile Extension award of the Wisconsin Association of County Agricultural Agents, the Pound Extension Award and the Alfred Toepfer Faculty Fellow Award from the University of Wisconsin College of Agriculture and Life Sciences, the Distinguished Achievement Award from the University of Florida School of Natural Resources and Environment, and the Foundation Scholar Award in Dairy Production from the American Dairy Science Association.

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